1998

# Characterization and Biodegradation of Crawfish and Agricultural Processing By-Product Compost.

Mounir Yehia Minkara
*Louisiana State University and Agricultural & Mechanical College*

# INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

**The quality of this reproduction is dependent upon the quality of the copy submitted.** Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

**UMI**

A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor MI 48106-1346 USA
313/761-4700 800/521-0600

# CHARACTERIZATION AND BIODEGRADATION OF CRAWFISH AND AGRICULTURAL PROCESSING BY-PRODUCT COMPOST

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Interdepartmental Program in Engineering Science

by
Mounir Yehia Minkara
B.S., University of Georgia, 1991
M.S., Auburn University, 1994
M.S., Louisiana State University, 1997
May, 1998

UMI
300 North Zeeb Road
Ann Arbor, MI 48103

ACKNOWLEDGMENTS

An appreciation and recognition to Dr. Thomas B. Lawson for providing me the opportunity to pursue my Ph.D. His guidance and support throughout my study and research program were remarkable toward my achievement.

A great thanks to my precious graduate committee members: Dr. Caye M. Drapcho, Dr. Gary A. Breitenbeck, Dr. Ralph J. Portier, Dr. Martin A. Hjortso, and Dr. Stephen A. Harrison. A special appreciation to Dr. Breitenbeck for the contribution that he provided in reviewing earlier manuscripts and providing his laboratory for my use. The laboratory assistance of Mr. David Schellinger was greatly appreciated.

I am very grateful to Dr. Lalit R. Verma and all the staff and the faculty members of the Biological and Agricultural Engineering Department for their support. Thanks are specially due to Ms. Louise Braud and Mr. Jonathan Scott for their contribution toward my research work.

My gratitude to LSU Agricultural Center and Louisiana Department of Environmental Quality for providing grant to support my research and my assistantship.

Foremost, my love and warm appreciation to my parents, brothers, and sister for their exemplary support. Finally, I am very thankful to God for His grace and benevolence during my studies and stay in Baton Rouge.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

## ABSTRACT

Disposal of crawfish processing wastes poses a challenging problem to the rapidly expanding crawfish industry. Co-composting is examined as a waste management alternative to landfill disposal. Wood chips, rice hulls, bagasse, and bark were evaluated for use as bulking agent in composting crawfish processing residuals. Use of bagasse as a bulking agents led to the largest reduction in volatile solids, organic-C, particle size, and compost volume. Finished compost using bagasse contained the greatest concentration of N. Self-heating patterns and decomposition of crawfish residuals were satisfactory using all four bulking agents. The finished products of all compost mixtures were stable and possessed good structure.

Leachate and runoff management from compost constitutes a challenging problem for compost facility designers and operators. The problem is extended where highly putrescent materials, such as fisheries processing residues, are composted. Nutrient losses through leaching and rainfall runoff were evaluated over a 50-day period in a pilot-scale windrow composting study. Crawfish processing residuals and rice hulls were mixed in a 1:1 ratio by weight and the mixture was windrowed on liners to capture leachate and runoff. Water for moistening the windrows was supplied by 1) leachate and runoff for one windrow; 2) tap water for the second; and 3) naturally-occurring rainfall events for the third. It can be beneficial to add leachate and runoff water to the pile during early stages of composting to provide adequate moisture and replenish some of the nutrients that could have been lost otherwise.

Degradation of mass, microbial activity, and nutrient content was determined during composting of different mixtures of rice hulls and crawfish residuals. This experiment was also undertaken to assess the suitability of recycling compost product with additional crawfish residuals. Mixtures containing high percentage of crawfish residuals had the highest degradability, microbial activity, and nutrient content. The reuse of the recycled product induced higher degradation in the recycled product as well as complete degradation of the crawfish residuals.

# CHAPTER 1

# INTRODUCTION AND OBJECTIVES

## 1.1 Introduction

By-products of seafood related industries are highly organic and putrescent. They could easily create environmental problems if they are improperly managed. Composting seafood by-products is a viable option that could turn the by-products into an asset instead of a liability. Composting is a waste management system that converts fresh organic materials into a stable, salable product by the action of microorganisms.

Composting nitrogenous materials with high moisture content such as fish waste requires a bulking agent that will absorb the moisture, increase porosity, absorb odor, and provide a carbonaceous source to sustain microbial activity. Determining the best combination of different ingredients is critical to the quality of the finished product and the success of the operation. Characteristic of the compost process is highly dependent on feedstock and operating conditions. Monitoring changes in compost composition during composting can improve process performance and optimize design parameters.

Leachate and runoff management is essential in any successful composting operation. Leachate and runoff from compost piles can contain substantial amounts of organic and inorganic pollutants that could have detrimental effects on the surrounding environment. Leachate and rainfall runoff management constitutes a challenging problem especially when composting nutrient-rich materials such as fisheries by-products.

Co-composting lignocellulotic agricultural by-products with seafood residuals can transform these by-products into valuable resources. Seafood residuals are typically rich in nitrogen and readily-degradable carbon whereas agricultural by-products are high in carbon. To dispose of large volumes of seafood residuals, such as crawfish residuals, requires an understanding of the biodegradation process during composting. Once most of the N and the readily degradable C are consumed, the decomposition rate slows down. Adding more crawfish residuals drives the composting process further. Reuse of the composted materials for additional composting of crawfish residuals is cost effective since it requires less storage capacity and handling operation. Repetitive use of such a product could make composting putrescent materials such as seafood waste very efficient and increases N content of the final compost product. Understanding the biodegradability and nutrient retention using such by-products can lead to optimized compost processing and consistently produce high quality finished compost.

## 1.2 Objectives

This study was conducted to characterize and analyze the performance and determine the biodegradability of composting crawfish residuals with agricultural by-products. A schematic of the research outline is shown in Figure 1.1. The main objectives were to:

1) Assess the potential of composting crawfish residuals using four materials (wood chips, rice hulls, bagasse, and bark) as bulking agents. Several physical and chemical characteristics of compost mixtures were monitored to compare the efficacy of the composting process and the quality of final products.

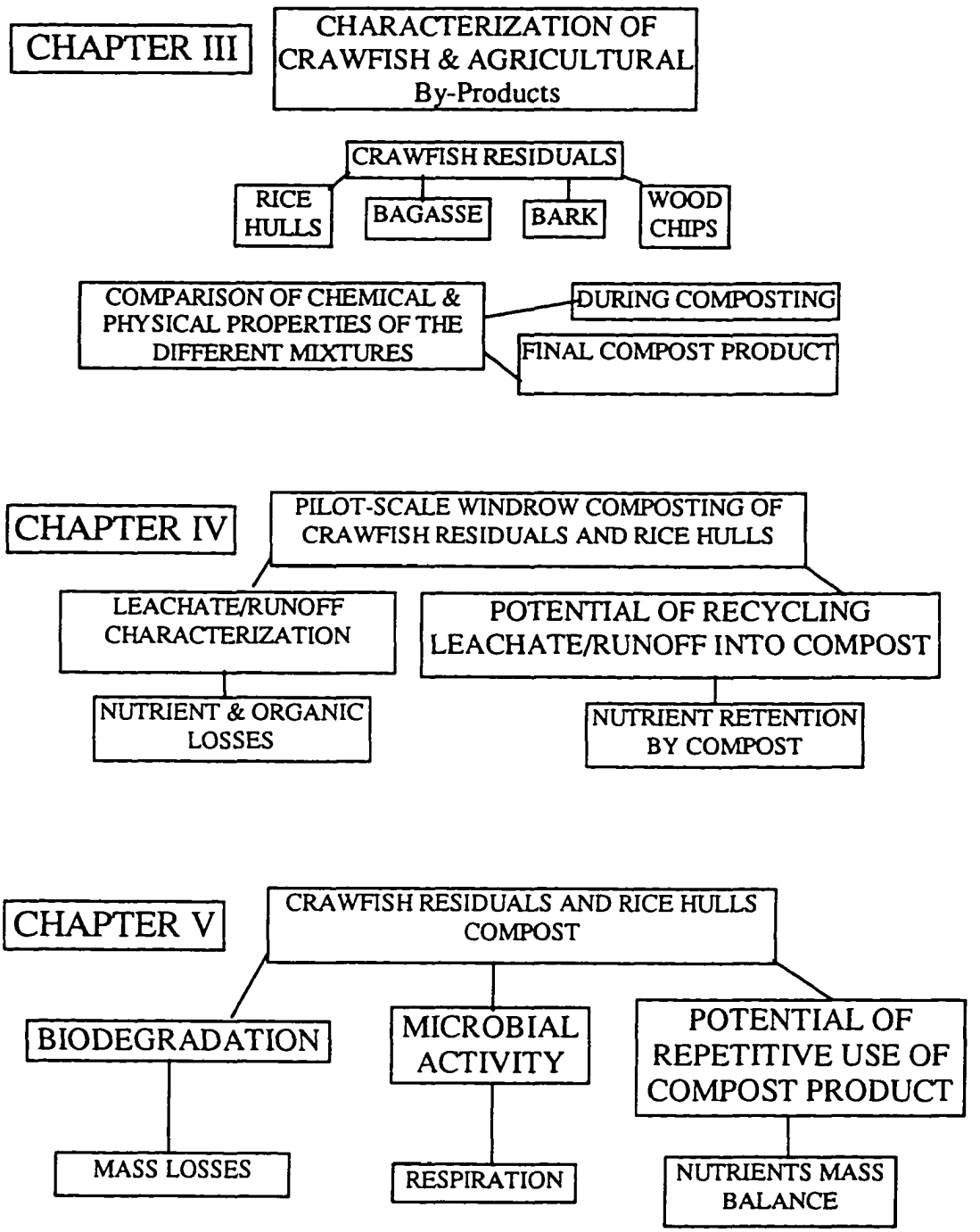



Figure 1.1. A schematic of the research outline.

2) Characterize the leachate and runoff from composting crawfish residuals with rice hulls, quantify nutrient losses, and examine the feasibility of recycling the leachate and runoff to the compost pile.

3) Determine the degradability and end points of composting crawfish residuals with rice hulls and the potential of repetitive use of compost product for additional crawfish residuals composting.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Composting as a Best Management Practice for Food Processing By-Products

### General Overview

Composting is a waste management system where biological processes take place where microorganisms convert organic materials into a product called compost. The end product could be either a soil- or mulch-like material. Microorganisms use carbon, nitrogen, oxygen, water, and nutrients to degrade organic materials. In waste disposal, composting is the most useful output strategy devised. Organic residues from municipal, commercial, and agricultural sources can be converted into a beneficial compost product. This product can be land applied to increase soil organic matter, reduce or eliminate chemicals use, provide plant nutrients, and improve soil structure. Other uses of compost include soil reclamation and bioremediation. Composting is seen as a means of waste disposal treatment and high quality product formation.

Composting has in fact three major applications: the production of compost for agricultural or horticultural use, the production of a selective crop (e.g. mushrooms), and the treatment of organic wastes. The treatment of organic wastes can include yard waste, municipal solid waste, sewage sludge, agricultural and food processing by-products, or even hazardous waste, which could be carried out in conjunction with the production of compost product (Miller, 1992).

Composting ecosystems are matrix-phase systems, with a high substrate density, in which metabolic heat generation produces thermophilic and mesophilic

conditions. Composting is predominantly an aerobic process where a diverse microbial population carries out organic matter decomposition. Microbial analyses in composting research have generally identified bacteria, actinomycetes, and fungi communities (Finstein and Morris, 1975). The composting ecosystem is sensitive to selective physical and chemical factors that include temperature, carbon, nitrogen, moisture, oxygen, bulk density, substrate availability, pH, and presence of inhibiting agents.

## Recovery of Organic Wastes by Composting

Compostable organic wastes are classified into four major categories: agricultural, municipal, food processing, and sewage sludge. In the United States, total production of organic wastes is estimated at more than 1.6 billion tons annually (Goldstein, 1993).

Agricultural organic waste is generated mainly from animal husbandry operations and crop production. Composting of animal manure has expanded substantially over the last 10 years and continues to increase due to more stringent regulations for land application of manure, plus increasing opportunities to compost off-farm materials (Kashmanian and Rynk, 1995). Agricultural composting is not limited to manure. Composting of farm mortalities is an emerging practice. Approximately 5,000 poultry farms in the top 25 poultry producing states composted their mortalities as of mid-1994 (Kashmanian and Rynk, 1995). Following the success in composting poultry mortalities, there is growing interest in composting swine and dairy mortalities. Carcasses less than 15 kg are composted whole, while larger ones

are dismembered, with their abdomens opened and diaphrams punctured to expose more surface area to microbial activity (Morrow et al., 1995).

Along with manure and farm animal mortalities composting, agricultural crop residues are composted either as amendments for other materials (manure, sludge, etc.) or as the major feedstock. Recently, more crop residues have become subjected to composting. Composting has been employed in numerous regions to process and recycle straw, cotton gin trash, cull potatoes, seed screenings, fruit and vegetable residues, and many others. Most crop residues cannot be applied directly to land because they may contain weed seeds, plant pathogens, and/or pesticide residues. They may also putrefy, generate nuisance and odors, and attract vectors (insects, flies, birds, rodents, etc.). Direct land application of crop residues that are high in carbon to nitrogen ratio (C:N) immobilizes soil N and hence inhibits plant growth. Therefore, it necessitates that composting be adopted to stabilize crop residues before they are used as soil amendments.

Food processing companies naturally generate much a higher percentage of biodegradable organic wastes than do many other industries. Typically, 10 to 30% of the incoming raw materials in the food processing industry become waste rather than a value-added product (Lowe and Buckmaster, 1995). Efficient, inexpensive, and environmentally sound utilization of these materials is becoming more important as regulations eliminate some of the current disposal practices. Food processing companies also face challenges to reduce the cost of disposal. Processing wastes may consist of a variety of by-products such as processing sludge, wastewater, wasted

product, animal and plant scraps, where, all have great potential as feedstock in composting.

Lately, yard waste has taken a wide turn in its management. Yard waste composting has become inevitable as more and more states are banning disposal of yard trimmings in landfills (Kashmanian, 1993). Yard waste consists primarily of tree trimmings, leaves and grass clippings. The fraction of municipal solid waste (MSW) which is yard waste in the United States has dropped from 24.5% in 1960 to 14.0% in 1995 (U.S. Environmental Protection Agency, 1996). This reduction is mainly attributed to large operations and backyard composting programs.

Composting of sewage sludge is now being conducted successfully by an increasing number of municipalities throughout the country while many others are seriously examining the practice. Composting is considered an alternative to landfill disposal and incineration. Composting sewage sludge offers several advantages: 1) oxidation of organic matter to a stable finished product, 2) destruction of human pathogens, 3) decreasing sludge volume and weight, and 4) generating a product free of noxious odor, safe for storage and land application, and beneficial for plant growth (U.S. Environmental Protection Agency, 1980).

Composting technology has been considered a valid option for bioremediation of contaminated substrates. The composting environment may increase the possibility for degradation of specific contaminants such as hydrocarbons due to elevated temperatures, the opportunity for co-oxidation, and the diversity of the microflora present (Crawford et al., 1993). Successful laboratory testing and field testing have

been conducted for soils contaminated with hazardous materials. Hazardous organic compounds may be intentionally combined with compostable materials for the purpose of detoxifying the waste. This application requires blending contaminated matrices such as soil with compostable biomass to achieve destruction of the hazardous materials. For example, composting explosives-contaminated soil has proven effective at significantly reducing the concentration of extractable explosives (Williams and Keehan, 1993).

## Beneficial Use of Compost Product

Many beneficial effects of compost have been reported. Examples are enhancement of plant growth, improving physical, chemical, and microbiological properties of soils, and suppressing soil-borne diseases.

Chen et al. (1996) reported that the application of biosolids and cow manure compost on rye provided a sufficient and a balanced source of nutrition for plant growth. The compost provided all major and minor nutrients essential for plant growth. Maynard (1994) suggested that chicken manure compost can be used as a substitute for inorganic fertilizer in an intensive cropping system to provide most, if not all, of the nutrient requirement for tomatoes, eggplant, peppers, broccoli, and cauliflower.

Increasing demand and rising costs for peat as a potting medium in horticulture have led to a search for high-quality and low-cost substitutes. Compost derived from organic waste materials such as yard waste, MSW, sewage sludge, spent mushroom, animal manure, and others could be used as a potting medium. Kostov et al. (1996)

produced tomato seedlings on compost mixtures and compost from vine branches, grape pruning, husks and seeds. The results showed that the seedlings grown on compost or compost mixtures had a higher dry matter content, total mass, length and diameter of stems, and number of leaves than plants grown on peat. Also, those seedlings were ready to be transplanted four to five days earlier than those grown on peat. In another study, researchers found that citrus seedlings grown in a sugarcane filtercake compost amended media had increased plant height, shoot weight, and greater leaf N than seedlings grown in 100 % peat medium (Stoffella et al., 1996).

The quality of produce grown with compost mixtures often is enhanced in terms of improved storage performance and superior sensory quality. For example, the taste quality and acid concentration of different varieties of tomatoes were better for those grown in compost substrates as compared to a mixture of commercial potting soil containing 40% clay and 60% peat (Vogtmann et al., 1993).

Several types of compost have been shown to be effective in suppressing various soilborne plant diseases, including fungi and nematodes (Hoitink and Fahy, 1986; Malek and Gartner, 1975). Results of green pepper amended with MSW and olive pomace composts had lower numbers of root-knot nematodes compared to unamended control soil (Marull et al., 1997).

Other beneficial uses of compost are in reclamation of disturbed or poor soils. Soil chemical, physical and biological properties can be beneficially altered by the addition of organic matter. A greenhouse study by Tripepi et al. (1996) showed that soil amended with composted paper sludge decreased soil bulk density, whereas soil

aeration, water-holding capacity, and porosity increased with an increase in the compost application rate. The addition of compost to soil increases organic matter and plant nutrients. The long-term experiment by Suzuki et al. (1990) reveals that total soil C and N concentrations are gradually increased by compost additions. The application of compost adds not only organic matter containing mineral compounds, but also it adds living organisms. Increases in populations of beneficial bacteria, actinomycetes, fungi, and celluloytic organisms were observed in the rhizosphere soil amended with sewage sludge compost (Pera et al., 1983).

Maturity of compost critically affects its successful utilization. This is especially important when compost is applied immediately before planting a crop or when it is used in container media. Immature compost induces high microbial activity in soil after application causing oxygen deficiency and a variety of indirect toxicity problems to plants (Zuccioni et al., 1981). Hence, the compost end product should be rich in humic matter and should have reduced and stable organic matter.

## 2.2 Feasibility of Composting Seafood By-Products

### Background

By-products of seafood related industries are highly organic and putrescent. These materials typically cause environmental problems if they are not properly discarded. Traditional disposal methods such as landfilling and offshore and near-shore dumping are no longer feasible. This has faced the seafood industry to find environmentally responsible alternatives for disposal or utilization of their by-products. Seafood by-products include crustacean shells, viscera, fish frames with or

without skin and scales, aquaculture and processing sludge, by-catch, and mortalities. Current disposal problems are attributed to limited access to landfills and high tipping fees, along with the intense odors produced and the impact on surface and ground water quality. Seafood by-products are generated in processing plants, fish farms, fishing vessels, marinas, and campgrounds. By-products of shellfish processing represent 70-80% of the mass. Finfish by-products vary between 55-65% of the mass. Some of the seafood by-products are used as bait or converted to feed and fertilizers through drying, liquefaction or ensiling, or rendered for oil. Fishmeal and rendering plants emissions are malodorous and the profit markets for fish silage, hydrolyses, and oils are limited and undependable. Composting is a simple, inexpensive, and low technology method of converting seafood by-products into stable and valuable product that could be used as a soil conditioner.

## Current Methodology

Various methods of composting have been developed and used in the treatment of seafood processing by-products (Mathur et al., 1988). Liao et al. (1994) used a passive aeration static pile method to compost salmon mortalities using sawdust as the bulking agent. The reactor was filled by alternating layers of mortalities with layers of sawdust. The experiment was run for five months before the piles were mixed. The authors found that this layered static pile method is suitable for composting feedstock that do not readily lend themselves to mixing. They also concluded that passive aeration is appropriate for composting layered salmon mortalities with sawdust up to a height of 1.20 m.

Brodie et al. (1994) developed a small-scale procedure to compost blue crab processing residuals using pine sawdust as the bulking agent. A one to one volume ratio of crab to sawdust resulted in a C:N ratio of 18:1. The compost product was recycled twice with new batch of crab by-products in a volume ratio of 2:1 compost to crab. The final product had total N, $NH_4$-N, $P_2O_4$, $K_2O$ and Ca concentration of 15.5, 4.1, 19.0, 4.4, and 107 g/kg, respectively, after 60 days.

Brinton and Seekins (1988) concluded that the mechanically aerated windrow method performed better than forced aerated static-piles of different fish by-products composted with sawdust and horse litter. Uneven heating and excessive drying were observed in the forced aerated static-piles. However, in all composts, fish parts decomposed completely in 50 days.

## Choosing the Right Bulking Agent

Cathcart et al. (1984) compared different mixture ratios of crab waste to straw corresponding to C:N ratios of 8:1, 15:1, 18:1, 20:1, 24:1, and 30:1. Temperature profiles of all were similar except for the 15:1 C:N ratio mixture which was the lowest, especially after the fifth day. The mixture having initial C:N ratio of 24:1 provided the greatest percent reduction in dry matter of about 36%.

Beside the use of sawdust and straw as bulking agents for composting seafood by-products, other research has focused on utilizing peat moss as the principal carbonaceous ingredient. Peat moss is favored because of its high moisture retention and superiority in stabilizing ammonia and odor emitted from seafood by-products (Liao et al., 1995). Although peat moss might be in plentiful supply in some parts of

the world, peat is a non-renewable resource and requires excavation; therefore, it tends to be expensive. The performance of three-bulking agents (peat moss, sawdust, and wood shavings) in composting fish offal was conducted by Liao et al. (1995). The authors used a 5:1 ratio by weight (fish to bulking agent). They found that if peat moss is used, the final product, at the end of the 150-day composting and maturation period, contains the highest average total N concentration of 59.2 g/kg compared to 37.7 and 2.73 g/kg for compost with sawdust and wood shavings, respectively. This suggested that the compost with peat moss would have the highest fertilizer value.

To prevent odor and fly problems, fisheries by-products should be incorporated into compost piles with bulking agent immediately. The pile should be covered with a 20-40 cm deep layer (blanket) of bulking agent or finished compost to prevent odor and vector problems (Frederick et al., 1991). Baker et al. (1992) noted that using peat moss or sawdust alone would cause oxygen depletion that created odors and fly problems. Sawdust and peat moss have limited ability to provide enough bulk for air space in the mixture. Thorough mixing of fish by-products with bulking agent could reduce wet pockets and, hence, reduce the formation of offensive odors (Brinton, 1994). Materials that resist decomposition, such as straw, bagasse, rice hulls, bark, and wood chips, retain good physical structure and improve porosity; therefore, they are more favorable than sawdust, wood shavings, or peat moss.

Johnson et al. (1991) compared compost derived from salmonid fisheries by-products and peat moss having different C:N ratios with a commercial potting mix (W. R. Grace forestry mix). The composts having initial C:N ratios of 14:1 and 18:1 had

physical properties similar to the commercial mix. The compost with an initial C:N ratio of 8:1 had the lowest available water content and low air space. On the other hand, nutrient concentrations of composts having initial C:N ratios of 8:1 and 14:1 were higher than that recommended for container media.

Jellum and Kuo (1991) produced high quality compost using ground bottomfish by-products combined with either red alder or Douglas fir sawdust. Grass yield using ground bottomfish by-products compost was higher than that in sewage sludge or steer manure composts, or ammonium nitrate fertilized soil. Also, the decomposition rate of groundfish residuals with sawdust compost was very rapid when incorporated under field conditions. However, decomposition was slow under extensive leaching in either bark or soil mixture in greenhouse experiment.

## 2.3 Leachate as a Potential Problem in Composting

Leachate and runoff management is essential in any successful composting operation. Leachate and runoff from compost piles could contain substantial amount of organic and inorganic pollutants that could have a detrimental effect on the surrounding environment. Nutrient and organic losses from composting facilities could lead to contamination of soils and surface and ground waters. For example, municipal and yard wastes often contain substantial amounts of nutrients, metals, herbicides, insecticides, and fungicides (Kovacic et al., 1992). These substances could easily leach into ground water during and after the composting process. Odor and vector problems develop when ponding results from leachate and runoff accumulation.

Christensen (1983) reported that the total amount of N leached from PVC columns containing MSW and sludge compost during two years accounted for 7-16%

of the N initially present in the compost. The author found that total N, $NH_4$, and $NO_3$ concentrations in leachate were in the range of 40-400 mg N/L, 5-350 mg $NH_4$-N/L, and 100-500 mg $NO_3$-N/L, respectively.

In digested sewage sludge and MSW composting, the concentration of fecal coliforms in the leachate tends to be high (about $6x10^8$ MPN/g dry weight) during the early period of composting period and decreases toward the end of the period (20 MPN/g dry weight) (Cooper and Golueke, 1979). The authors suggested that this was due to heat inactivation. It is very critical that leachate produced during the early stages of composting be minimized and treated before it is discharged or used.

Ulen (1993) characterized the leachate from a compost mixture of dairy manure and straw having C:N ratio of 16:1 using 50 kg straw and one metric ton of manure. Leaching and surface runoff were measured separately. Over a seven-month period, the total amount of N, P, and K leached were 200 g $N/m^3$, 23 g $P/m^3$, and 1,100 g $K/m^3$ of manure, respectively, measured during the winter. Surface runoff nutrient transport was less than the leaching losses and totaled 8 g $N/m^3$, 2 g $P/m^3$, and 98 g $K/m^3$ of manure.

Nienaber and Ferguson (1992) measured the leachate at different soil depths from cattle manure compost over three- and seven-year periods. Concentration of $NO_3$ at the end of the seven-year period was greater than the three-year period in depth between 0.75 and 4.0 m below the composting ground. Also, nitrate and chloride concentrations appeared to be greater beneath the compost ground than beneath an adjacent furrow irrigated cornfield throughout the 7.5 m soil profile sampled. Surface soil (0.15 m) samples from the compost site indicated extremely high salt content

leading to possible soil fertility and salinity problems. The electrical conductivity (EC) of the soil in the adjacent cornfield was 0.86 mmho/cm, which is within the normal range. The EC for the surface soil (0.15m) beneath the compost for the seven-year and the three-year periods were 3.04 mmho/cm and 2.80 mmho/cm, respectively.

Ballestero and Douglas (1996) compared N transport in the ground water from farm waste (horse bedding) and yard waste (grass clippings and leaves) compost windrows, cleared and undisturbed forest lands, and soils adjacent to the compost sites. $NO_3$-N concentration increased by an order of magnitude between each of the sites and the compost facilities. $NO_3$-N directely beneath the windrow reached a high concentration of 900 mg/L at the 1.5 m depth. $NH_4$-N concentration exceeded 700 mg/L at the 0.6 m depth. The authors estimated that the farm waste compost lost 24% of its initial N whereas yard waste lost about 4%.

Diaz and Trezek (1979) composted MSW and digested sewage sludge in windrows for 16-, 32-, and 50-day periods. Samples were thereafter placed in lysimeters (1.52 m long x 0.91 m diameter) and brought to saturation in seven to 11 days. To collect leachate, the compost in lysimeters received 1 cm tap water per week. The 16- and 32-day composts had a maximum $NO_3$-N concentration of about 500 mg/L after 11 weeks of leaching. Immediately after leaching the 16- and 32-day composts contained the highest $NH_4$-N concentration of about 860 mg/L. Also, the highest chemical oxygen demand (COD) values were observed during the earliest period of leaching with values ranging between 29,000 and 59,000 mg/L. The initial concentration of Na and $PO_4$-P in the leachate from units containing the 16-day

compost ranged from 1,200-4,000 and 34-90 mg/L, respectively. A general trend was observed reflecting the decline in concentrations of most metals in leachate with the compost age and the period of leaching.

A controlled column study was performed by Rymshaw et al. (1992) to evaluate and compare the absorptive capacity of various bulking agents. Wood chips and newspaper mixture, sawdust, and straw retained approximately similar volumes of water, 50-90%, 72-93%, and 62-88%, respectively, when composted with animal manure over 21 weeks. In another experiment, the authors composted bull manure with sawdust and wood shavings in windrows over a 53-day period. Ammonium N, nitrate N, organic N, and total N concentrations in the leachate fluctuated between 8 and 40 mg/L, 3 and 15 mg/L, 21 and 747 mg/L, 22 and 1,548 mg/L, respectively. In runoff, ammonium N and nitrate N concentrations were below 10 mg/L and organic N and total N were below 11 and 38 mg/L, respectively. Total organic C remained very high in the leachate, but decreased, as the compost became stable. Total organic C values ranged between 2,460 and 14,175 mg/L. In runoff, total organic C concentrations were substantially lower, i.e., 30-413 mg/L. Biochemical oxygen demand (BOD) varied between 95 and 1,278 mg/L in the leachate and between 0 and 91 mg/L in runoff. Leachate $PO_4$ concentration was measured only on the 8th week and found to be 75.9 mg/L. In runoff, $PO_4$ concentration was measured during the 7th and 10th week where it ranged between 2.8-26.4 mg/L.

Aqueous emissions from composting facilities must be treated before they can be discharged into the environment. When designing compost facilities, a

comprehensive management plan should include leachate assessment, soil analysis, and surface- and ground water monitoring. Water analysis should include, at a minimum, nutrients such as N and P, trace elements, heavy metals, organics, and coliforms. Soil analysis helps assess nutrients and metal build-up. Leachate and runoff control measures may involve impermeable padding, vegetative filter strips or constructed wetlands, sedimentation basins, oxidation ponds, the use of spray irrigation systems, and/or recycle systems.

## 2.4 Biodegradation of Lignocellulotic Materials during Composting

### Nature of Lignocellulotic Materials

Lignocellulose is a complex of the polymers lignin, cellulose and hemicellulose. Cellulose is a linear polymer of repeating glucose units, linked by $\beta$(1-4) glycosidic bonds. Hemicellulose is the collective name for a group of branched heteropolysaccharides containing the hexoses glucose, mannose and galactose and the pentoses xylose and arabinose. Lignin is an aromatic polymer of phenylpropane units, based upon p-coumaryl, coniferyl and sinapyl alcohols.

Materials with high lignocellulotic content are the most abundant of renewable organic resources. These recalcitrant materials are characterized by slow degradation rates under normal conditions. The concentration of lignin in such material is a major factor controlling organic matter decomposition (Crawford, 1976). Lignin is relatively recalcitrant compared with cellulose and hemicellulose. In many lignocelluloses, a portion of the cellulosic fraction is tightly bound to the lignin, making that component only moderately available.

## Factors Influencing Biodegradation of Organic Materials

Degradation rates depend on initial and process conditions. These include temperature, oxygen, moisture content, particle size, carbon (C) content, nitrogen (N) content, the form of carbon present (i.e., soluble C, cellulose, or lignin), population and type of microorganisms, and pH. The proper temperature is a very important parameter in the aerobic decomposition process. The optimum temperature has generally been reported to range between 45-65°C (Regan and Jeris, 1970). During active composting, Rynk (1992) reported that moisture content should be maintained between 40-65% for optimum degradation. The preferred pH for the spectrum of microorganisms involved in composting is in the range of 6.5-8.0. Air must be supplied to maintain enough oxygen for microbial respiration, heat exchange and moisture removal (Haug, 1993).

Lignocelluloses usually provide the principal C and energy substrate for compost microorganisms. Compost system design is highly dependent on knowing the degradability or substrate availability of the feedstock. The time required to complete the composting process (i.e. the solid retention time) is dependent on the readily available substrate. Some bulking agents used to adjust moisture and porosity may contain high percentages of C but may contribute little to the overall available substrate in the mixture for microbial consumption. Organic matter with similar C:N ratios, such as straw and wood, will decompose at very different rates simply because of differences in the C forms.

During composting, the readily degradable fractions (i.e. starches or simple sugars) are consumed first leading to mineralization of organic matter. Later in the

process less degradable compounds (i.e. cellulose or lignin) are then partially consumed. In the maturation period, organic matter is humified into more stable compounds.

The amount of lignin degraded by microorganisms is directly proportional to the amount of cellulose available to the microorganisms (Odier and Monties, 1983; Reid and Deschamps, 1991). This indicates that adding more material rich in cellulose and N to the compost may degrade the lignin material further. Adding a degradable C source rich in N to materials high in lignin would provide nutrients and energy to microorganisms responsible for biodegradation. Entry and Backman (1995) found that the addition of both easily degradable C and N in the soil improves lignin degradation. However, adding N without readily degradable C increased cellulose degradation but not lignin degradation, since microorganisms require additional sources of energy to decompose lignin (Kirk and Farrell, 1987).

### Methodology for Determining Substrate Degradation

Substrate biodegradability is very useful for compost process design and operation. It is used to determine: (a) the amount of substrate energy available to drive the composting process, (b) the requirement for additional amendments, (c) the aeration demand, and (d) the final product mass (Haug, 1993). Several methods for estimating substrate degradability are used. The major methods are: (1) material mass balance, (2) carbon loss, (3) volatile solids loss, (4) $CO_2$ production, (5) oxygen consumption, (6) change in chemical oxygen demand (COD), (7) substrate utilization, and (8) spectroscopical analyses.

(1) Material Mass Balance

Degradation of organic matter is generally determined by mass balance weighing the infeed and output materials. The mass loss during the process represents the total degradation. This method is not always practical and cost effective during composting due to handling of different feedstock and the large volume produced. Jhorar et al. (1991) used the mass balance method to determine dry mass and nutrients (N, P, and K) loss from composting rice straw with glue waste at different C:N ratios.

(2) Carbon Loss

Total organic C test is based on complete combustion of organic matter. Combustion of matter will convert organic C into $CO_2$. The $CO_2$ is measured directly by a nondispersuive infrared analyzer (APHA et al., 1992).

(3) Volatile Solids Loss

Volatile solids concentration, the percent of dry solids lost by ignition at 550 °C, is widely used as a rough measure of organic matter (APHA et al., 1992). Aerobic biological activity decreases the volatile solids content by converting organic C to $CO_2$. Therefore, volatile solids measurements during composting would serve as a rate parameter of biodegradation.

(4) $CO_2$ Production

During composting, fresh organic materials are mineralized into $CO_2$ and $H_2O$ and humified into a stable material. Composting can be represented in general terms by the following reaction:

$$\text{fresh organic matter} + O_2 \xrightarrow{\text{microbial action}} \text{stabilized organic matter} + CO_2 + H_2O + \text{heat}$$

The rate of $CO_2$ produced is used to estimate organic matter decomposition rate (Bach et al., 1984).

(5) Oxygen Consumption

Oxygen consumption is a direct indication of microbial activities. Rate of $O_2$ uptake is also used to estimate organic matter decomposition and to indicate compost product stability (Haug and Ellsworth, 1991). Specific oxygen uptake rate (SOUR) is the rate of $O_2$ consumed by microbes for each unit of dry mass or organic matter.

(6) Change in COD

Aerobic biological decomposition decreases the capacity of the organic material to reduce chemical reactants, such as potassium dichromate; hence a COD test might serve to assess decomposition rate (Lossin, 1971). The compost product would have a lower COD both per unit weight and per unit C than the initial mixture.

(7) Substrate Utilization

Substrate in compost includes components (lignin, cellulose, hemicellulose, etc.) that vary considerably in degradability. Making use of standard models of microbiology, the model equations of the kinetics of matter conversion, substrate utilization, and microbial growth could be used to estimate substrate components degradation (Kaiser, 1996).

(8) Spectroscopical Analyses

The degradability of organic material depends mainly on the chemical composition of its organic fraction. Spectroscopical analyses of organic matter transformations during composting, such as Fourier transform infrared (FTIR) and carbon-13 nuclear magnetic resonance (13C-NMR) spectroscopy, are used to provide

estimates of the change in contents of aliphatic compounds, carbohydrates, aromatic and phenolic moieties, and carboxyl concentration (Chen and Inbar, 1993).

### Substrate Degradation Methods Used

The aforementioned biodegradation tests could be applied, in principle, to any compost feedstock stream. Volatile solids test is a direct method for determining the change in organic matter and ash content of composting material. $CO_2$ production and oxygen consumption rates indicate microbial activity and hence they display compost process performance. $CO_2$ production and oxygen consumption tests are also used to determine compost stability.

## 2.5 References

American Public Health Association (APHA), American Water Works Association, and Water Pollution Control Federation. 1992. Standard methods for the examination of water and wastewater. 18th edition. APHA, Washington, D.C.

Bach, P. D., M. Shoda, and H. Kubota. 1984. Rate of composting of dewatered sewage sludge in continuously mixed isothermal reactor. Journal of Fermentation Technology, 62(3):285-292.

Baker, D. R., T. Halbach, and R. L. Stauffer. 1992. Composting recreational fisheries by-products at Minnesota resorts. In: Proceedings of the 1991 Fisheries By-Products Composting Conference, UW Sea Grant Institute, Madison, WI. pp. 33-44.

Ballestero, T. P. and E. M. Douglas. 1996. Comparison between the nitrogen fluxes from composting farm wastes and composting yard wastes. Transactions of the ASAE, 39(5): 1709-1715.

Brinton, W. F. and M. D. Seekins. 1988. Composting fish by-products: A feasibility study. Time & Tide, RC &D, Mid-Coast Compost Consortium, Waldodoro, Maine.

Brinton, R. 1994. Low cost options for fish waste. Biocycle 35(3)68-70.

Brodie, H. L., L. E. Carr, and A. T. Tolley. 1994. Crab scrap compost demonstration. Transactions of the ASAE, 37(3):853-856.

Cathcart, T. P., D. Lipton, F. Wheaton, R. Brinsfield, D. Swartz, and I. Strand. 1984. Composting Blue-Crab Processing Waste. UM-SG-TS-84-01. Maryland Sea Grant Program, Univ. of Maryland, College Park, Maryland.

Chen, L., W. A. Dick, J. G. Streeter, and H. A. J. Hoitink. 1996. Ryegrass utilization of nutrients released from composted biosolids and cow manure. Compost Science and Utilization, 4(1)73-83.

Chen, Y. and Y. Inbar. 1993. Chemical and spectroscopical analyses of organic matter transformations during composting in relation to compost maturity. In Science and Engineering of Composting: Design, Envionmental, Microbiological and Utilization Aspects. Eds. Hoitink, H. A. and H. M. Keener. Worthington, OH. Renaissance Publications. pp. 551-600.

Christensen, T. H. 1983. Leaching from land disposed municipal composts: 2. Nitrogen. Waste Management & Research, 1:115-125.

Cooper, R. C. and C. G. Golueke. 1979. Survival of enteric bacteria and viruses in compost and its leachate. Compost Science/Land Utilization, v.20, March/April, 29-35.

Crawford, S. L. 1976. Microbial degradation of lignocelluioses: The lignin component. Applied Environmental Microbiology, 31:714-717.

Crawford, S. L., G. E. Johnson and F. E. Goetz. 1993. The potential for bioremediation of soils containing PAHs by composting. Compost Science and Utilization, 1(3)41-47.

Diaz, L. F. and G. J. Trezek. 1979. Chemical characteristics of leachate from refuse-sludge compost. Compost Science/Land Utilization, 20, May-June, 27-30.

Entry, J. A. and C. B. Backman. 1995. Influence of carbon and nitrogen on cellulose and lignin degradation in forest soils. Canadian Journal of Forestry Research, 25:1231-1236.

Finstein, M. S. and M. L. Morris. 1975. Microbiology of municipal solid waste composting. Advancement in Applied Microbiology, 19:113-151.

Frederick, L., R. Harris, L. Peterson, S. Kehrmeyer, M. Milner, and A. H. Miller. 1991. Preparation and use of compost from fisheries by-products. In: Proceedings of the 1991 Fisheries By-Products Composting Conference, UW Sea Grant Institute, Madison, WI pp. 13-20.

Goldstein, J. 1993. Needed: Regional inventories of organic residuals. Compost Science and Utilization, 1(1):13-19.

Haug, R. T. 1993. The practical handbook of compost engineering. Lewis Publishers, Boca Raton, Florida.

Haug, R. T. and W. F. Ellsworth. 1991. Measuring compost substrate degradability. Biocycle, 32(1):56-62.

Hoitink, H. A. J. and P.C. Fahy. 1986. Basis for the control of soilborne plant pathogens with composts. Annual Review of Phytopathogens, 24:93-114.

Jellum, E. J. and S. Kuo. 1991. Production and testing of composts containing fisheries by-products and sawdust. In: Proceedings of the 1991 Fisheries By-Products Composting Conference, UW Sea Grant Institute, Madison, WI. pp. 147-161.

Jhorar, B. S., V. Phogat, and R. S. Malik. 1991. Kinetics of composting rice straw with glue waste at different carbon:nitrogen ratios in a semiarid environment. Arid Soil Research and Rehabilitation, 5:297-306.

Johnson, K. W., T. J. Malterer, and T. E. Levar. 1991. The evaluation of peat-based fisheries by-products composts for use as horticultural container substrates. In: Proceedings of the 1991 Fisheries By-Products Composting Conference, UW Sea Grant Institute, Madison, WI. pp. 87-104.

Kaiser, J. 1996. Modelling composting as a microbial ecosystem: a simulation approach. Ecological Modelling, 91:25-37.

Kashmanian, R. M. 1993. Quantifying the amount of yard trimmings to be composted in the United States in 1996. Compost Science and Utilization, 1(3):22-29.

Kashmanian, R. M. and R. F. Rynk. 1995. Agricultural Composting in the United States. Compost Science and Utilization, 2(3):84-88.

Kirk, T. K. and R. L. Farrell. 1987. Enzymatic "combustion": The microbial degradation of lignin. Annual Review of Microbiology, 41:465-505.

Kostov, O., Y. Tzvetkov, N. Kaloianova, and O. Van Cleemput. 1996. Production of tomato seedlings on composts of vine branches and grape prunings, husks and seeds. Compost Science and Utilization, 4(2)56-61.

Kovacic, D. A., R. A. Cahill, and T. J. Bicki. 1992. Compost: Brown gold or toxic trouble? Environmental Science and Technology, 26(1)38-41.

Liao, P.H., A. T. Vizcarra, A. Chen and K. V. Lo. 1994. Composting of salmon farm mortalities with passive aeration. Compost Science and Utilization, 2(4)58-66.

Liao, P.H., A. T. Vizcarra, A. Chen and K. V. Lo. 1995. A comparison of different bulking agents for the composting of fish offal. Compost Science and Utilization, 3(2)80-86.
Lossin, R. D. 1971. Measurement of the chemical oxygen demand of compost. Compost Science, v. 12, March/April, 31-32.

Lowe, E. D. and D. R. Buckmaster. 1995. Dewatering makes big difference in compost strategies. Biocycle, 36(1): 78-82.

Malek, R. B. and J. B. Gartner. 1975. Hardwood bark as a soil amendment for suppression of plant parasitic nematodes on container-grown plants. Hortscience, 15:173-178.

Marull, J., J. Pinochet, and R. Rodriguez-Kabana. 1997. Agricultural and municipal compost residues for control of root-knot nematodes in tomato and peper. Compost Science and Utilization, 5(1)6-15.

Mathur, S. P., J. Y. Daigle, J. L. Brooks, M. Levesque, and J. Arsenault. 1988. Composting seafood wastes. Biocycle, 29(9) 44-48.

Maynard, A. A. 1994. Sustained vegetable production for three years using composted animal manures. Compost Science and Utilization, 2(1)88-96.

Miller, F. C. 1992. Composting as a process based on the control of ecologically selective factors. In: *Soil Microbial Ecology* by F. B. Metting Jr., (ed.), Marcel Dekker, New York, p. 514-544.

Morrow, W., P. O'Quinn, J. Baker, G. Erickson, K. Post, and M. McGraw. 1995. Composting as a suitable technique for managing swine mortalities. Swine Health and Production, 3(6)236-243.

Nienaber, J. A. and R. B. Ferguson. 1992. Nitrate movement beneath a beef cattle manure composting site. ASAE paper No. 922619. St. Joseph, MI.

Odier, E. and B. Monties. 1983. Absence of microbial mineralization of lignin in anaerobic enrichment cultures. Applied Environmental Microbiology, 46:661-665.

Pera, A., G. Vallini, I. Sireno, M. L. Bianchin, and M. de Bertoldi. 1983. Effect of organic matter on rhizosphere microorganisms and root development of sorghum plants in two different soils. Plant and Soil, 74:3-18.

Regan, R. W. and J. S. Jeris. 1970. A review of the decomposition of cellulose and refuse. Compost Science, v. 11, January/February, 17-20.

Reid, I. D. and A. M. Deschamps. 1991. Nutritional regulation of synthetic lignin (DHP) degradation by the selective white rot fungus *Phelbia (Merulius) tremellosa*: Effects of glucose and other cosubstrates. Canadian Journal of Botany, 69:147-155.

Rymshaw, E., M. F. Walter, and T. L. Richard. 1992. Agricultural composting: Environmental monitoring and management practices. Department of Agricultural Engineering, Cornell University, Ithaca, NY.

Rynk, R. 1992. On-farm composting handbook. NRAES-54, Northeast Regional Agricultural Engineering Service, Ithaca, NY.

Stoffella P. J., Y. Li, D. V. Calvert, and D. A. Graetz. 1996. Soilless growing media amended with sugarcane filtercake compost for citrus rootstock production. Compost Science and Utilization, 4(2):21-25.

Suzuki, M., K. Kamekawa, S. Sekiya, and H. Shiga. 1990. Effect of continuous application of organic and inorganic fertilizer for sisty years on soil fertility and rice yield in paddy field. In Transactions of the 14th International Congress of Soil Science, v.IV, Kyoto, Japan. pp. 14-19.

Tripepi, R. R., X. Zhang, and A. G. Campbell. 1996. Use of raw and composted paper sludge as a soil additive or mulch for cottonwood plants. Compost Science and Utilization, 4(2): 26-36.

Ulén, B. 1993. Losses of nutrients through leaching and surface runoff from manure-containing composts. Biological Agriculture and Horticulture, 10:29-37.

U.S. Environmental Protection Agency. 1980. Manual for composting sewage sludge by the Beltsville aerated-pile method. EPA-600/8-80-22. Office of Research and Development, Cincinnati, Ohio.

U.S. Environmental Protection Agency. 1996. Characterization of municpal solid waste in the United States: 1996 update. EPA/530-R-97-015. Office of Solid Waste and Emergency Response, Washington, D.C.

Vogtmann, H., K. Matthies, B. Kehres, and A. Mier-Ploeger. 1993. Enhanced food quality: Effects of composts on the quality of plant foods. Compost Science and Utilization, 1(1): 82-100.

Williams, R. T. and K. R. Keehan. 1993. Hazardous and industrial waste composting. In Science and Engineering of Composting: Design, Envionmental, Microbiological and Utilization Aspects. Eds. Hoitink, H. A. and H. M. Keener. Worthington, OH. Renaissance Publications. pp. 363-382.

Zuccioni, F., A. Pera, M. Forte, and M. de Bertoldi. 1981. Evaluating toxicity of immature compost. Biocycle, 22:54-57.

# CHAPTER 3

# CO-COMPOSTING OF CRAWFISH AND AGRICULTURAL PROCESSING BY-PRODUCTS[1]

## 3.1 Introduction

Crawfish production is a rapidly expanding industry in the world especially in southern United States and China (U.S. Department of Commerce, 1996). Louisiana, the principal crawfish-producing state, produced 43,800 metric tons (MT) of crawfish, in 1995 (Louisiana Cooperative Extension Service, 1995). Only the tail meat of the crustacean is consumed, while the exoskeleton and intestines are discarded. Because only 15-20% of whole crawfish is edible, more than 35,000 MT of processing residuals are discarded annually. Crawfish exoskeleton is rich in chitin, a natural polymer of amino sugars. Crawfish residuals are highly putrescent and readily attract insects and vermin. When left to decay on the ground, they generate an organic leachate that can pollute surface and ground water. These characteristics render the current practice of landfill disposal unsatisfactory. Composting of crawfish residuals is a potentially practical and environmentally sound disposal alternative.

Unless crawfish residuals are blended with an appropriate bulking agent, piles of these materials rapidly become anaerobic and generate noxious odors. A suitable bulking agent provides sufficient porosity for air exchange, absorbency for moisture retention and odor filtration, and favorable thermal properties. Bulking agents that serve as substrate for the microorganisms responsible for organic decomposition may stimulate initial self-heating. Costs and regional availability of suitable materials usually

[1] Reprinted by permission of Compost Science & Utilization (Appendix C).

dominate their use as bulking agents. Many agricultural processing by-products such as wood chips, rice hulls, bagasse and bark are produced in large volumes in areas commonly used for crawfish production. In Louisiana, about 170 thousand MT of rice hulls (rice mill by-product), 1.2 million MT of bagasse (sugar cane mill by-product), and 4.3 million MT of wood by-products (including bark, wood chips and sawdust) are generated annually (Kleit et al 1994). A portion of the volume of these by-products is used as biomass fuel, but their heat index values are sometimes marginal for this use. Despite a few other limited uses, large volumes of these materials are available at low cost for recycling as bulking agents for composting.

The objective of this study was to assess the potential of composting crawfish residuals using four materials (wood chips, rice hulls, bagasse, and bark) as bulking agents. Several physical and chemical characteristics of compost mixtures were monitored to compare the efficacy of the composting process and the quality of final products.

## 3.2 Materials and Methods

Crawfish residuals were co-composted with each of the four bulking agents for 50 days in 0.3-$m^3$ commercially available reactors fabricated from recycled plastic (Barclay Recycling Inc., Ontario, Canada). Crawfish residuals were mixed 1:5 v/v with pine wood chips and rice hulls and 1:6.5 v/v with bagasse and bark (pine and cottonwood) (Table 3.1). Three replicates of each mixture having were made. The bulk density, organic carbon (C) and total nitrogen (N) concentrations, and moisture content of these materials were determined prior to use (Table 3.2).

Table 3.1. Volume, mass, and carbon to nitrogen (C:N) ratios of wood chips, rice hulls, bagasse, and bark co-composted with crawfish residuals.

| Mixture | Volume | Mass | C:N |
|---|---|---|---|
| | (w w*) | | (d w^) |
| Wood Chips:Crawfish | 5.0:1 | 2.7:1 | 143.5 |
| Rice Hulls:Crawfish | 5.0:1 | 1.1:1 | 47.3 |
| Bagasse:Crawfish | 6.5:1 | 1.2:1 | 38.5 |
| Bark:Crawfish | 6.5:1 | 3.2:1 | 55.8 |

* Wet weight
^ Dry weight

Table 3.2. Characteristics of raw bulking agents and crawfish residuals.

| Material | Bulk Density | Organic C | Total N | C:N | Moisture Content |
|---|---|---|---|---|---|
| | ($kg/m^3$ ww*) | (g/kg dw^) | | | (% ww) |
| Wood Chips | 255.8 | 475.9 | 2.29 | 207.8 | 10.4 |
| Rice Hulls | 104.4 | 372.0 | 4.84 | 76.9 | 9.5 |
| Bagasse | 81.4 | 436.3 | 9.28 | 47.0 | 53.4 |
| Bark | 218.5 | 442.8 | 10.74 | 41.2 | 39.2 |
| Crawfish | 466.4 | 317.3 | 50.3 | 6.3 | 66.2 |

* Wet weight
^ Dry weight

Compost temperature was measured using copper-constantan thermocouples connected to a CR7 Datalogger (Campell Scientific, Logan, UT). Thermocouples were positioned at three equally-spaced depth (d) of the height (H) of the mixture in the center of each reactor (Figure 3.1). The mean height of compost in each reactor was measured twice weekly for volume reduction determination prior to collecting samples. Approximately 150-g sample from each of the 12 reactors was collected for analysis. Data reported are the means of three replicates. Samples were initially used for gravimetric determination of moisture content (APHA et al., 1992). Particle size, after drying, was determined by screening each sample through a series of sieves vibrating for 5 min. Sieves opening sizes were 25.4, 12.7, 9.5, 6.4, 2.36, 1.65, 0.83, and 0.59 mm. To facilitate comparisons, the mean particle size was calculated using the percentage weight of material retained by different sieves. After sieving, samples were ground (150 mesh), thoroughly mixed and stored in air-tight containers. Approximately 5-g subsamples were combusted at 550 °C to determine volatile solids content. A mixture of 1:2 w/w compost to water was used to determine pH using a Corning model 250 Ion Analyzer (Corning, NY). Approximately 20-mg subsamples were used for organic C and total N determination using a Heraeus model CHN-O Rapid Analyzer. Nitrate ($NO_3$) and ammonium ($NH_4$) concentrations were determined in KCl extracts using a Wescan model 360 Analyzer (Wescan Instrument Inc., Deerfield, IL).

Water was added to compost mixtures as needed to maintain moisture contents between 40-60%. The mixtures were turned manually 17 days and 38 days after initially blending the material in the reactors. Percent oxygen in the compost piles was

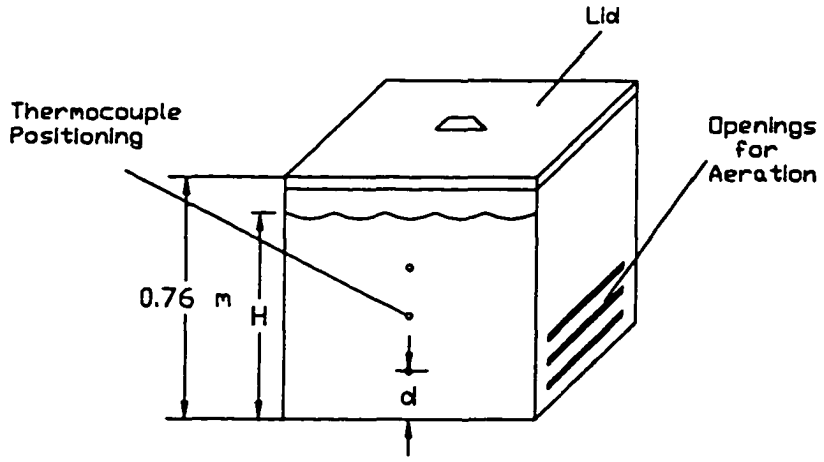



Figure 3.1. Description of the bench scale reactor used to co-compost crawfish residuals and four different bulking agents (H - height of mixture; d = H/4).

measured three times weekly using a model OT-21 oxygen probe (Demista Instruments, Wheeling, IL). Oxygen measurements showed that the perforations on the lower side of the reactors were sufficient to maintain adequate aeration [19-21% $O_2$ (v/v)] in all reactors throughout the study. A 30-cm outer layer of bulking agent was maintained during the first 17 d to serve as a biofilter for odor and nuisance control. A moderate ammonia ($NH_3$) odor was evident for the first 10-14 days, and when turning the mixtures, but diminished thereafter. The outer layer proved to be effective in controlling flies and other nuisance.

3.3 Results and Discussion

**Moisture Content, Temperature, and Volatile Solids Losses**

Moisture content remained in the desirable range (40-60%) during the composting process for all mixtures, except for the rice hulls that initially did not retain water as well as the other mixtures tested. The maximum initial moisture content obtained for a single rice hull mixture was 30%. After turning on the 17$^{th}$ day, moisture content consistently remained between 40-60%. Degradation of crawfish residuals apparently facilitated moisture retention by rice hulls.

Although moisture contents during the early stages of composting were not in the range typically recommended for optimal composting (Rynk, 1992), the rice hull mixtures achieved the most rapid self-heating and highest initial average temperatures (Figure 3.2), possibly because the lower moisture content of this mixture resulted in more effective heat retention. Bagasse mixtures attained the highest average temperature during the rest of the thermophilic period (third week). The corresponding temperature profiles of wood chip and bark mixtures were 5-10 °C

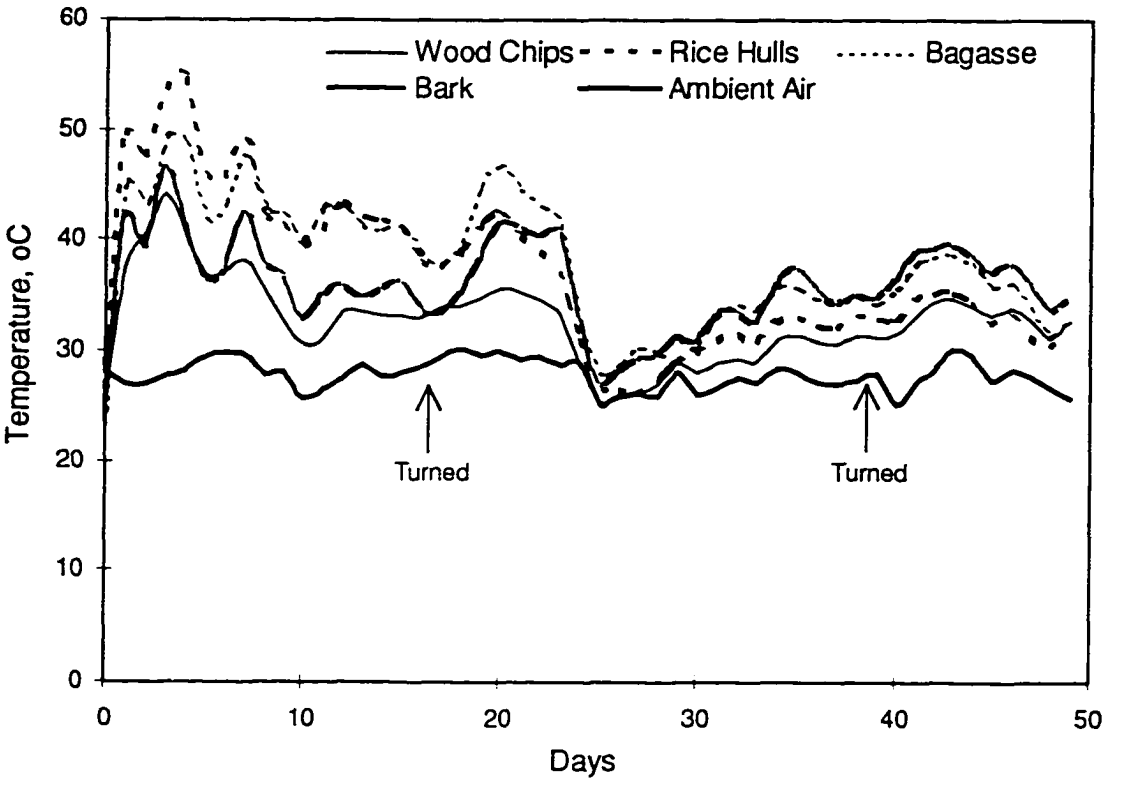



Figure 3.2. Variation of compost mixtures and ambient air temperatures with time (days) during the 50-day study.

lower than those of rice hull or bagasse. After 23 d, temperatures in all reactors rapidly declined to near ambient temperature probably due to the microbial consumption of most of the readily available substrate. Thereafter, temperatures rose 2-15 °C but remained in the upper mesophilic range (between 25 and 40 °C). When the experiment was terminated after 50 d, temperatures in all mixtures were close to one another.

Over the first two weeks, rice hull mixtures had the largest significant reduction in volatile solids of 17.4% ($P=0.0019$, $\alpha=0.05$) (Figure 3.3 and Appendix A: Table A.1). This explains the initial high temperatures measured in the rice hull mixtures. After the second week, when the compost was turned, the bagasse mixtures had a sharp reduction in volatile solids (20.1%) which corresponded to the sudden increase in temperature. By the end of the experiment, bagasse mixtures lost an average of 27.6% of their initial volatile solids. Rice hull and bark mixtures lost an average of 22.6% and 21.3%, respectively, of their initial volatile solids. Wood chip mixtures lost the lowest amounts of volatile solids (12.1%). This explained the lowest temperature profile during the first three weeks. Rice hull and bark mixtures offered the most readily mineralizable substrate for compost microorganisms during the first two weeks of the composting process. However, bagasse and wood chip mixtures offered the most readily mineralizable substrate after the second week. Of the four bulking agents studied, bagasse offered the largest reduction in volatile solids and the maximum available substrate ($P=2.40E-06$, $\alpha=0.05$) (Appendix A: Table A.2).

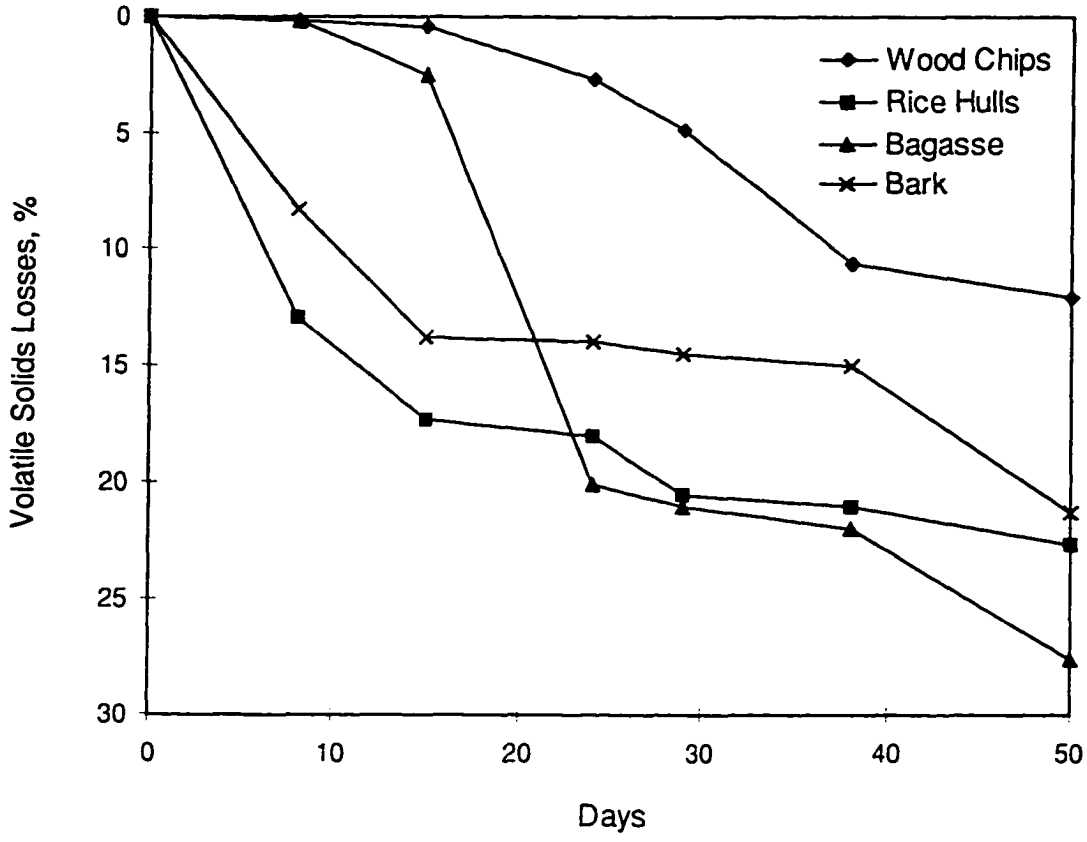



Figure 3.3. Compost mixtures volatile solids losses with time (days) during the 50-day study.

## Changes in Organic C, Total N, and C:N Ratio

Since changes in total weight occurred during the composting process and the rate of change differed among the compost mixtures studied, comparison of concentrations of constituents expressed on a total weight basis can be deceptive. Ash weight has been used as an internal standard to demonstrate changes in constituent composition because the inorganic fraction is largely conserved during composting (Haug, 1993). Change in the ratio of the weight of a constituent to that of ash, then, reflects the losses or gains of constituents relative to their initial amounts. Bagasse and bark mixtures lost an average of 55.3% and 49.4%, respectively, of their initial organic C contents on an ash basis (P=5.48E-07, $\alpha$=0.05) (Appendix A: Table A.3). Not surprisingly, wood chip and rice hull mixtures lost the lowest amounts of organic C (40.0% and 43.7%, respectively) due to their greater recalcitrance to microbial breakdown (Appendix A: Table A.3). Organic C seemed to be more readily available in bagasse mixtures than in any of the others.

Significant losses of N and other essential nutrients can occur during composting. For example, Witter and Lopez-Real (1987) reported N losses as high as 70% during composting of a wide array of feedstock. Such N losses are attributed to $NH_3$ volatilization as well as subsequent leaching of $NH_4$ and $NO_3$ (Soliva et al., 1993). Although $NH_3$ losses were not measured, nitrogen losses are explained by changes in total N concentrations of the mixtures based on total ash weight. Nitrogen losses were clearly evident during composting crawfish residuals with each of the bulking agents (Figure 3.4). Average total N concentrations (ash basis) were reduced for all mixtures after 50 d composting. Composting crawfish residuals with rice hulls,

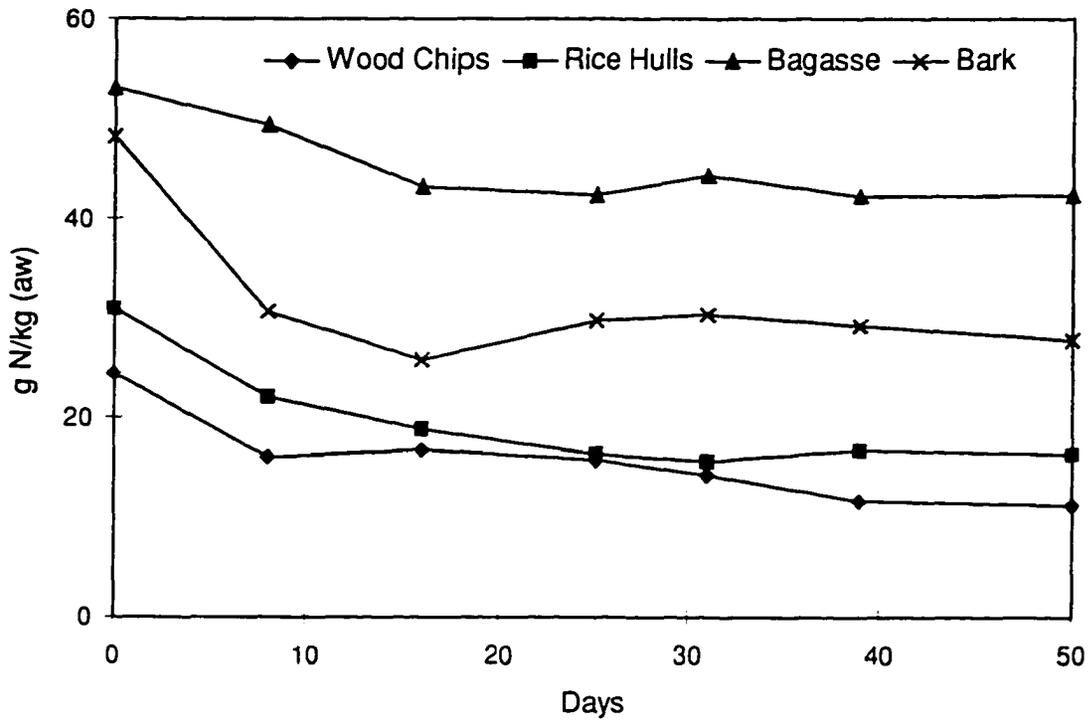



Figure 3.4. Total nitrogen (g N/kg compost ash weight) concentrations versus time (days).

bark and bagasse resulted in average losses of total N of 52.4% , 35.0% and 18.0% (ash basis), respectively, after 50 d ($P=0.25$, $\alpha=0.05$) (Appendix A: Table A.4). Despite the fact that wood chip mixtures had the highest C:N ratio (Figure 3.5) and the lowest initial total N concentration (Figure 3.6), they showed a great loss of average total N (47.7% ash basis) by the end of the experiment. On the other hand, although the bagasse mixtures had the lowest C:N ratio (Figure 3.5) and the highest total N concentration (Figure 3.6), their N losses were minimal. Because bagasse was the most degradable of the bulking agents, a greater portion of its N may have been retained as organic N thus reducing volatile losses of $NH_3$. Most N losses occurred during the early stages (first 15 d) of the process, which is typical in composting (Morisaki et al., 1989). Total N concentration (dry weight basis) showed very little variation during the 50-d period, with the exception of bagasse mixtures (Figure 3.6). Average total N concentration of bagasse mixtures steadily increased from an initial 11.5 g N/kg to a final concentration of 18.4 g N/kg after 50 d, an increase of 59.3% (Figure 3.6). This apparent increase was more likely due to the small loss of N relative to that of total organic matter than to gains in N via biological $N_2$ fixation or other mechanisms.

### Ammonium, Nitrate, and pH

Initial compost pH values were about 8.4 in both rice hull and bagasse mixtures and about 7.9 in both wood chip and bark mixtures (Figure 3.7). Changes in pH during composting followed a similar path for all mixtures. During the first 25 d, the pH was continuously decreasing to about 7.4 for bagasse and bark and 7.2 for wood chip and rice hull mixtures. This decrease in pH is probably due to organic N

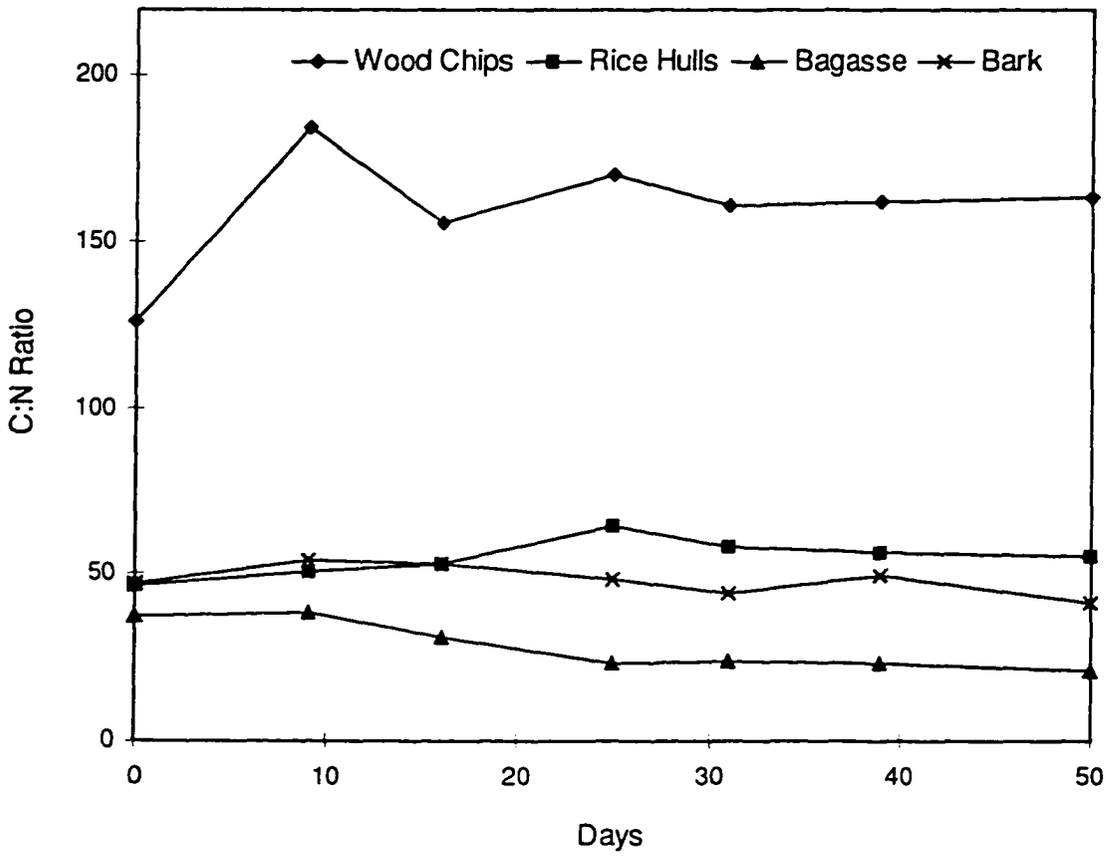



Figure 3.5. Variation of compost mixtures C:N ratio with time (days) during the 50-day study.

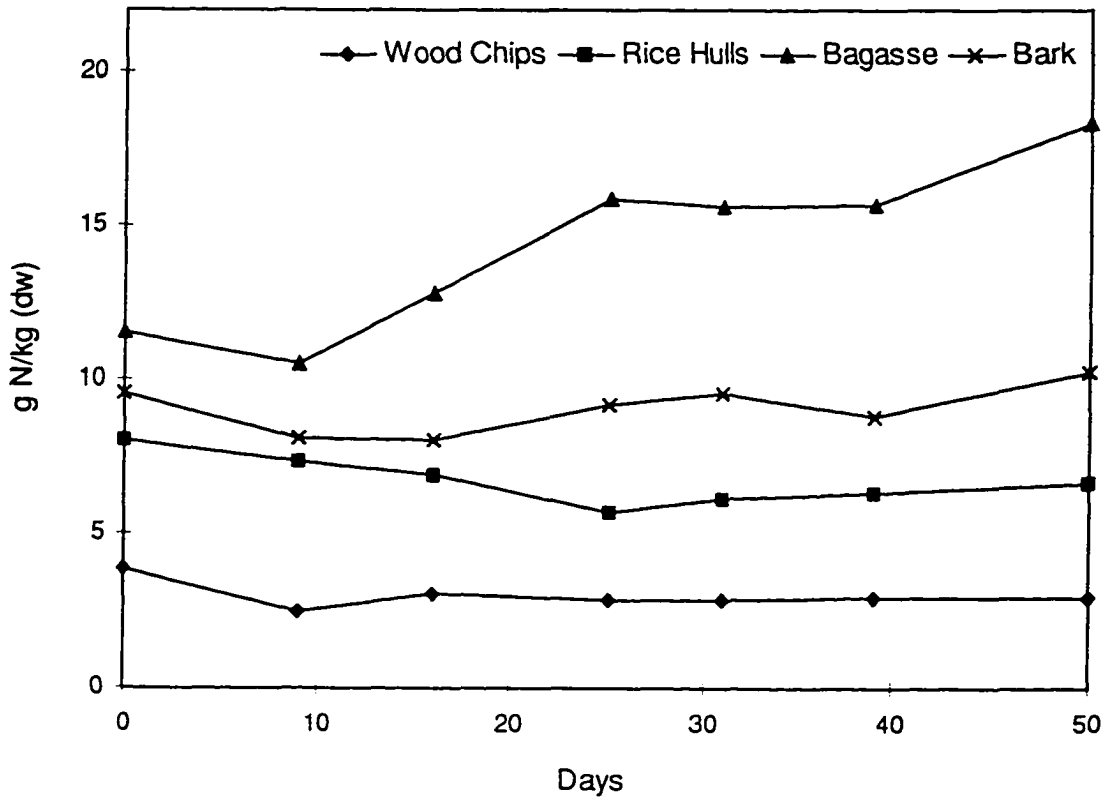



Figure 3.6. Total nitrogen (g N/kg compost dry weight) concentrations versus time (days).

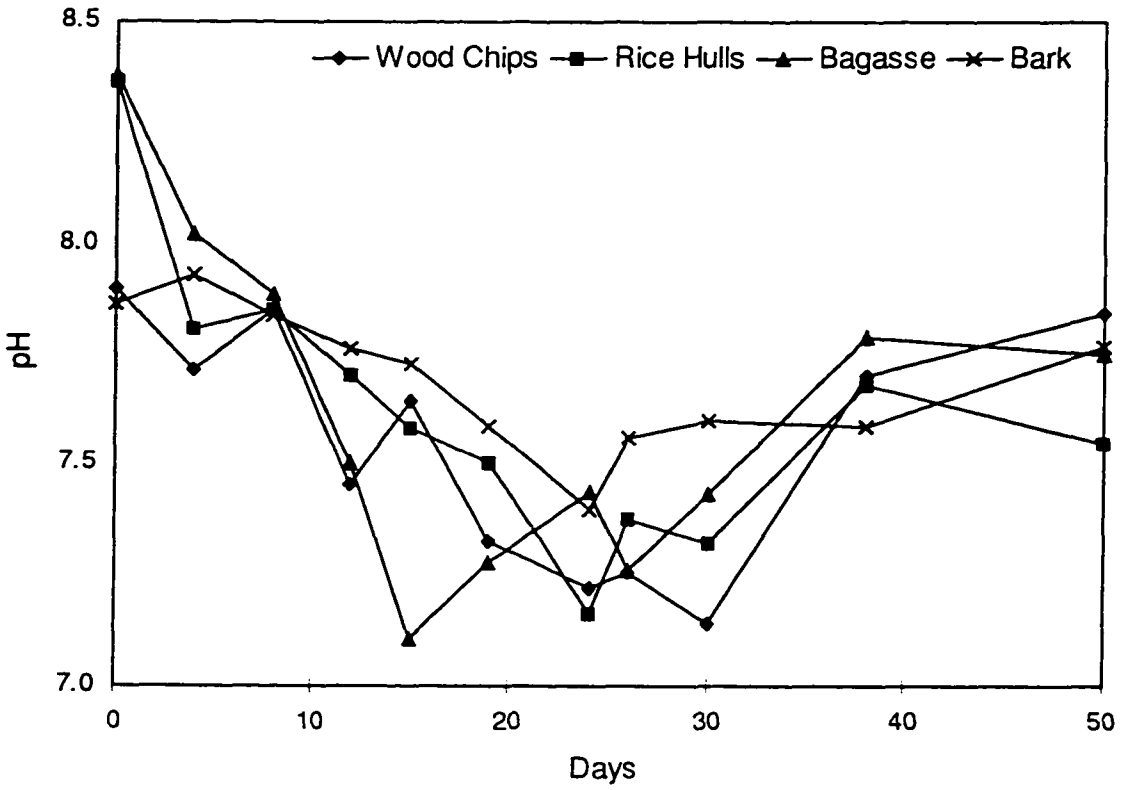



Figure 3.7. Variation of compost mixtures pH with time (days) during the 50-day study.

mineralization and the transient appearance of volatile organic acids (Miller, 1992). In the final 25 d, pH values increased to about 7.6 for rice hull, 7.8 for bagasse and bark, and 7.9 for wood chip mixtures.

During composting, microbial activities decompose organic matter and transform complex N compounds into mineral forms such as $NH_3$, $NH_4$, and $NO_3$. In crawfish residuals composting, this transformation produced $NH_4$ concentrations in the range of 10-400 mg $NH_4$-N/kg (Figure 3.8). Bagasse and bark mixtures maintained relatively high $NH_4$ concentrations during the last 20 d and contained 160 mg $NH_4$-N/kg and 76 mg $NH_4$-N/kg, respectively, at the end of the composting process. Final $NH_4$ concentrations of rice hull (18 mg $NH_4$-N/kg) and wood chip mixtures (3 mg $NH_4$-N/kg) were significantly lower. As heterotrophic demand for available N declines, accumulated $NH_4$ may undergo microbial oxidization to $NO_2$ and $NO_3$. During composting, $NO_3$ concentrations in bagasse and bark mixtures remained below 40 mg $NO_3$-N/kg (Figure 3.9). However, an increase in $NO_3$ concentrations was observed in rice hull and wood chip mixtures after 25 d. At the end of the experiment, rice hull mixtures contained the highest average $NO_3$ concentration (97.2 mg $NO_3$-N/kg). Concentration of $NO_3$ in wood chip mixtures declined to about 17 mg $NO_3$-N/kg during the last 12 d of the study. Throughout the experiment, $NH_4$ and $NO_3$ concentrations in bagasse mixture were consistently low, which support the hypothesis that greater immobilization of N may account for the lower losses of N from bagasse mixture. Bagasse appeared to be able to assimilate mineralized N more readily than bark, rice hulls, or wood chips.

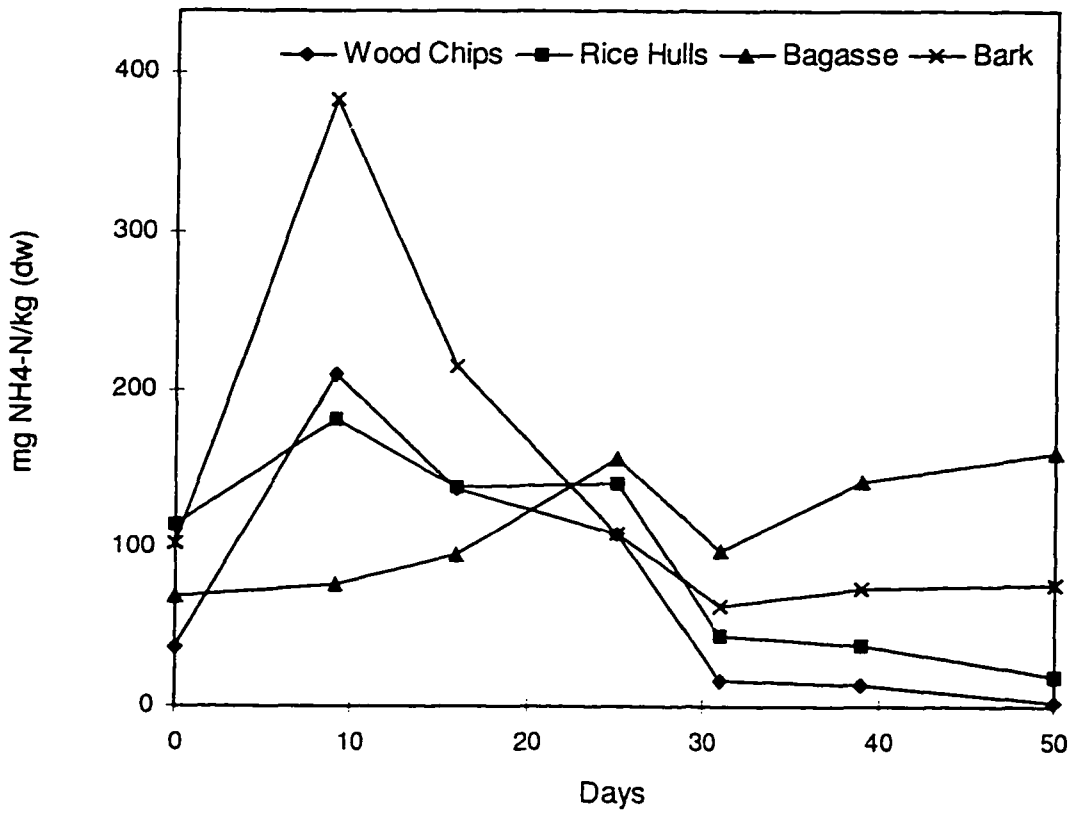



Figure 3.8. Ammonium (mg $NH_4$-N/kg compost dry weight) concentrations versus time (days).

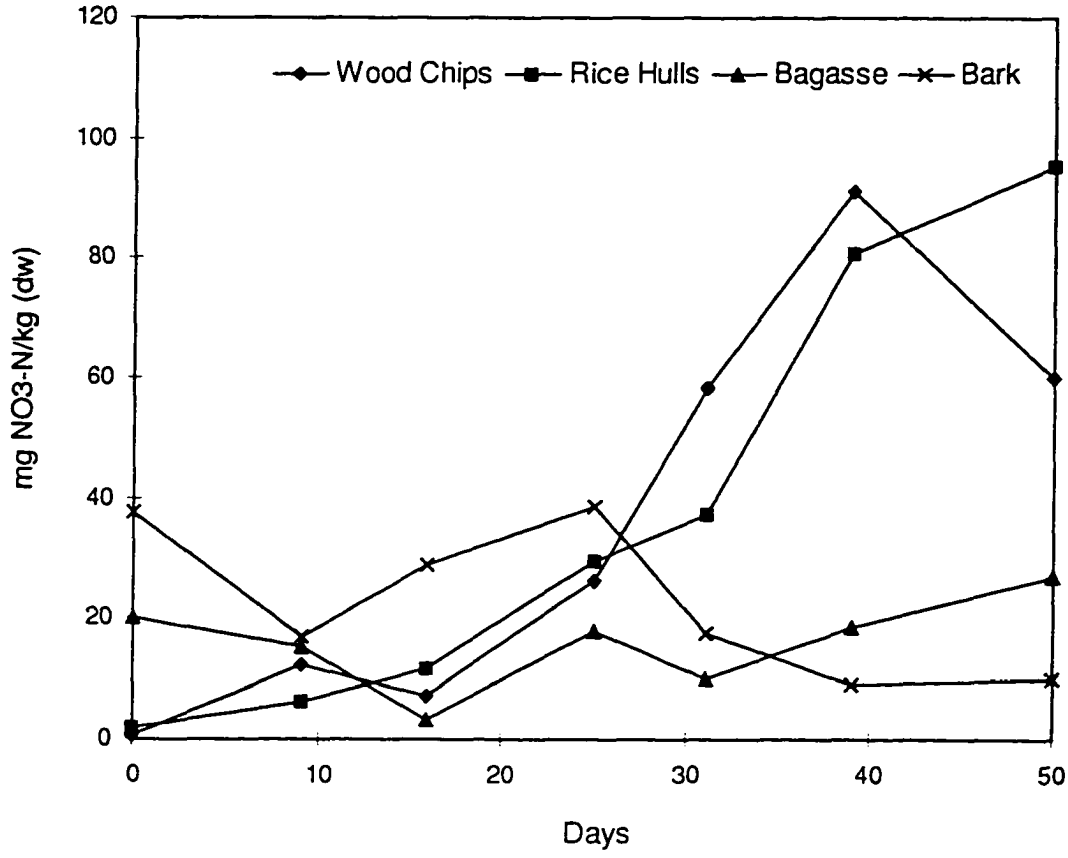



Figure 3.9. Nitrate (mg $NO_3$-N/kg compost dry weight) concentrations versus time (days).

### Particle Size and Volume Reductions

The mean particle size of organic mixtures reduces during composting due to degradation of the organic fraction. Bagasse mixtures had the greatest mean particle size reduction of 53.7% of the original bulking agent and 64.7% of the initial mixtures after 50 d (Table 3.3). Wood chip mixtures had the least reduction (24.2%) of the initial mixtures. Bark mixtures mean particle size was reduced by 45.7% of the initial mixtures and by 37.1% of the original bulking agent. Rice hulls final mean particle size was 1.69 mm reduced by about 60% of the initial mixtures size (4.23 mm) and reduced only by 1.2% of the original bulking agent size (1.71 mm). All degradation of rice hull mixtures is contributed to the degradation of crawfish residuals. Rice hulls have a silicon skeleton which contribute to their recalcitrance to microbial degradation (Lalche and Nash, 1983).

Volume of composted materials is reduced significantly during composting. The greatest overall volume reduction (52.8%) occurred in the bagasse mixtures while the least reduction (16.5%) occurred in the rice hull mixtures. Bark and wood chip mixtures volume reductions were 43.8% and 22.6%, respectively. The lower volume reduction of the rice hull and wood chip mixtures is due to the low degradability of the silicon and lignin contained in these materials. This could be considered an advantage in some situations where these materials could be reused as bulking agents in additional composting operations thus reducing the quantity of bulking agent required.

## 3.4 Conclusions

All bulking agents evaluated in this study worked well when co-composted with crawfish residuals. Co-composting crawfish residuals with bagasse resulted in

Table 3.3. Mean particle size (mm) of raw bulking agents and mixtures and mean particle size reductions after 50 days^.

| | Wood Chips | Rice Hulls | Bagasse | Bark |
|---|---|---|---|---|
| | Mean Particle Size, mm | | | |
| Bulking Agent | 5.3 | 1.7 | 5.1 | 8.5 |
| Initial Mixture | 6.2 | 4.2 | 6.7 | 9.9 |
| Mixture at 50 d | 4.7 | 1.7 | 2.4 | 5.3 |
| Reduction of mixture at 50 d | | | | |
| from bulking agent, % | 11.4 | 1.2 | 53.7 | 37.1 |
| from initial mixture, % | 24.2 | 60.0 | 64.7 | 45.7 |

^ Crawfish residuals size ranged between 2 and 75 mm.

the greatest reductions in volatile solids (27.6%) and organic C (55.3%), as well as in total volume shrinkage (52.8%) and mean particle size reductions (64.7%). The compost derived from the bagasse mixtures contained the highest nutrient content (18.4 g N/kg and 160 mg $NH_4$-N/kg). Rice hull mixtures resulted in the least total volume and mean particle size reductions, nevertheless, these mixtures maintained high $NO_3$ concentration and lost notable amounts of volatile solids. Bark mixtures were satisfactory in terms of volatile solids losses (21.3%) and final N content (10 g N/kg). Wood chip mixtures did not perform as well as the other bulking agents tested, nevertheless, crawfish residuals were completely decomposed during the 50-d study period.

If the goal of the process is to produce high quality compost, co-composting with bagasse appears preferable. However, if the goal is to dispose of large volumes of crawfish residuals, the use of rice hulls or wood chips as a bulking agent offers an advantage in that larger volume of crawfish residuals can be treated per volume of bulking agent. Reuse of the composted materials for additional composting of crawfish residuals could be cost effective. Using wood chips, rice hulls, bagasse, bark, or other suitable bulking agent for disposal of seafood processing residuals by composting appears to offer a practical solution. Biodegradability and nutrient retention using such by-products merit further study to optimize the compost process and to consistently produce high quality finished compost.

## 3.5 References

American Public Health Association (APHA), American Water Works Association, and Water Pollution Control Federation. 1992. Standard methods for the examination of water and wastewater. 18th edition. APHA, Washington, D.C.

Haug, R. T. 1993. The practical handbook of compost engineering. Lewis Publishers, Boca Raton, Florida.

Kleit S., C. F. de Hoop, and S. J. Chong. 1994. An overview of agriforestry waste production and use in Louisiana. Sixth National Bioenergy Conference, Reno/Sparks, Nevada.

Lalche, A. J. and V. E. Nash. 1983. A preliminary evaluation of composted rice hulls and arkalite as components of a container plant growing medium. Mississippi Nurseryman's Association, 1(4)21-32.

Louisiana Cooperative Extension Service. 1995. Louisiana Summary, Agriculture and Natural Resources, Louisiana State University, Baton Rouge, Louisiana.

Miller, F. C. 1992. Composting as a process based on the control of ecologically selective factors. In: *Soil Microbial Ecology* by F. B. Metting Jr., (ed.), Marcel Dekker, New York, p. 514-544.

Morisaki, N., C. C. Phae, K. Nakasaki, M. Shoda, and H. Kubota. 1989. Nitrogen transformation during thermophilic composting. Journal of Fermentation and Bioengineering, 67(1): 57-61.

Rynk, R. 1992. On-farm composting handbook. NRAES-54, Northeast Regional Agricultural Engineering Service, Ithaca, NY.

Soliva, M., F. Giro, and S. Manzano. 1993. Nitrogen lost during composting at two facilities in Spain. Compost Science and Utilization, 1(4): 23-26.

U.S. Department of Commerce, 1996. Bureau of the Census, Washington, D.C.

Witter, E. and J. M. Lopez-Real. 1987. The potential of sewage sludge and composting in a nitrogen recycling strategy for agriculture. Biological Agriculture and Horticulture, 5:1-23.

# CHAPTER 4

# LEACHATE AND RUNOFF CHARACTERIZATION DURING CRAWFISH PROCESSING RESIDUAL AND RICE HULL COMPOSTING

## 4.1 Introduction

Management of leachate and rainfall runoff poses a challenging problem for composting operations, especially those composting fisheries by-products. Fisheries by-products tend to be putrescent, rich in nutrients, and have a high water content. Moisture contents in the range of 60-80% are very common (Brinton and Seekins, 1988). If not properly managed, leachate from fisheries by-products compost creates foul odors, attract flies, or otherwise be aesthetically unacceptable (Frederick et al., 1989).

Windrow composting is a widely accepted practice for aerobic decomposition of many types of organic wastes. However, substantial amounts of nutrients may be lost in leachate and runoff from composting operations and threaten surface and groundwater quality (Ballestero and Douglas, 1996; Kovacic et al., 1992). Characterization of leachate from compost operations is required by many permitting agencies and is necessary in determining site design parameters to minimize odors and other problems (Andree, 1991). Problems caused by leachate can trigger fines or closures by permitting agencies.

Effective management strategies for reducing leachate composting of fisheries by-products are not well established. Commonly, bulking agents with moderate to high moisture absorbency such as peat and sawdust are mixed with fisheries by-products to reduce leachate generation during composting (Brinton

and Seekins, 1988). By reducing the amount of leachate and runoff, losses of inorganic nutrients and organic compounds can also be reduced (Ulén, 1993). Rice hulls are highly effective as a bulking agent for composting crawfish processing residuals (Chapter 3). Rice hulls are light weight, easily turned and because of their recalcitrance to microbial decomposition, may be reused to dispose of several loads of crawfish residuals. During their initial use, however, rice hulls resist wetting and are therefore more prone to produce leachate than other bulking agents.

Traditional leachate and runoff management techniques include storage and/or land application or discharge into a public sewer system. Recycling leachate by applying it to active compost piles for moisture control is an attractive, low-cost alternative (Spencer, 1991). This technique not only reduces the reliance on rainfall or the need for supplemental water sources, but also may mitigate environmental impacts by reducing the quantity of leachate as well as its nutrient content and biological oxygen demand. The principal objective of this study was to compare the quality and characteristics of leachate/runoff generated by uncovered windrows comprised of crawfish residuals and rice hulls when (1) watered with leachate; (2) watered with tap water; or (3) unwatered except for rainfall.

## 4.2 Materials and Methods

### Windrow Design

Pilot-scale windrows (3 m long x 1.5 m wide x 1.5 m height) were constructed on impermeable polyethylene liners placed on a 5:1 slope that channeled leachate and runoff into a 300 L collector (Figure 4.1). Three windrows were constructed: (1)

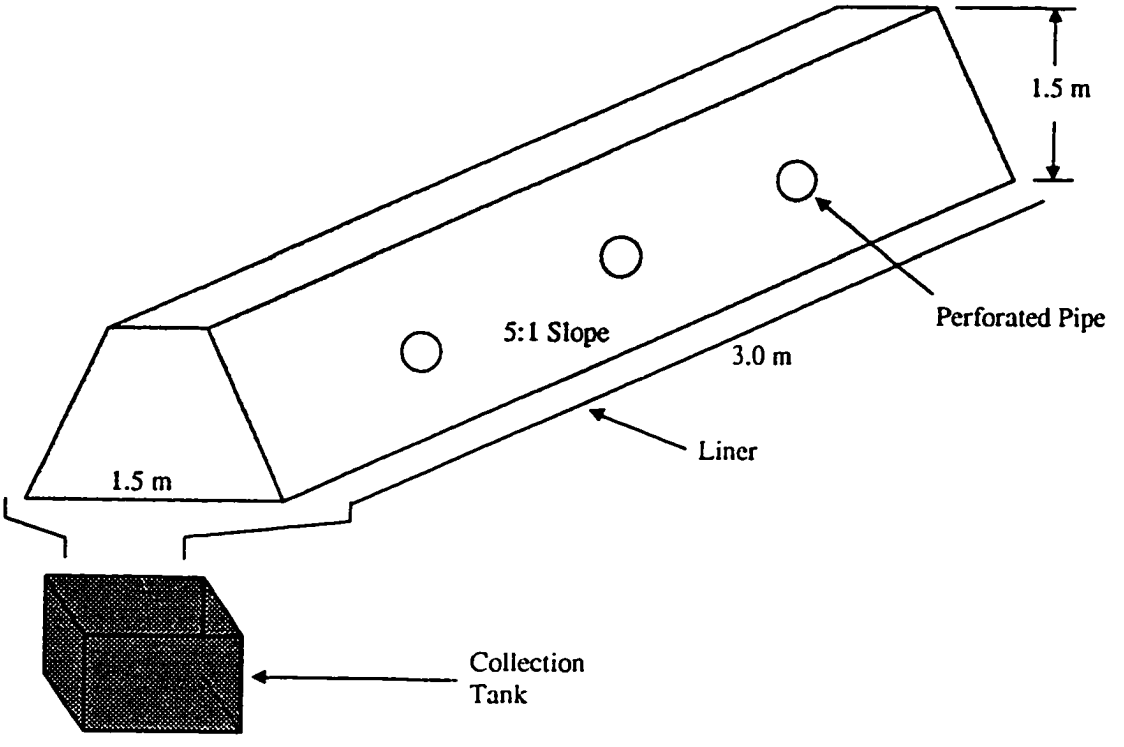



Figure 4.1. Windrow and leachate/runoff collector.

watered with leachate/runoff (L); (2) watered with tap water (W); and (3) unwatered except for rainfall (R).

The feedstock for each windrow consisted of 150 kg (wet weight) of crawfish residuals and 150 kg (wet weight) of rice hulls. The moisture content, bulk density, organic carbon (C) and total nitrogen (N) concentrations of these materials were determined prior to use (Table 4.1). Similar volume of the stored leachate/runoff or tap water was applied by sprinkler to the corresponding windrow as required to maintain adequate moisture content. Tap water and leachate/runoff were added on days: 2, 5, 8, 12, 19 and 30 to meet moisture microbial demand and drying criteria. The windrows were turned manually 19 days and 30 days after construction to homogenize the materials. Passive aeration was provided by three perforated PVC pipes (10 cm diameter) positioned laterally across each windrow. Oxygen concentration measurements showed that passive aeration was adequate to maintain aerobic conditions throughout the composting period.

### Leachate/Runoff and Compost Sampling Procedure

Leachate/runoff from the windrows were collected daily after each rainfall or watering event (Figure 4.2). Similar leachate/runoff volume was collected from each windrow. Triplicate leachate/runoff samples (~500 ml) were analyzed for pH, chemical oxygen demand (COD), nitrate ($NO_3$), ammonium ($NH_4$), and primary elements (Mg, Mn, Na, K, P, and S). Volume remained after sampling from the L collector was stored in a 900-L reservoir and used later for watering. Volume remained from the W and R collectors was discarded after sampling. Three compost samples (~50 g each) were collected twice weekly from each windrow middle

Table 4.1. Characteristics of rice hulls and crawfish residuals.

| Material | Moisture Content* % | Bulk Density* ($kg/m^3$) | Organic C (g/kg solids) | Total N | C:N |
|---|---|---|---|---|---|
| Rice Hulls | 9.5 | 104.4 | 372.0 | 4.8 | 76.9 |
| Crawfish | 66.2 | 466.4 | 317.3 | 50.3 | 6.3 |

* Moist basis

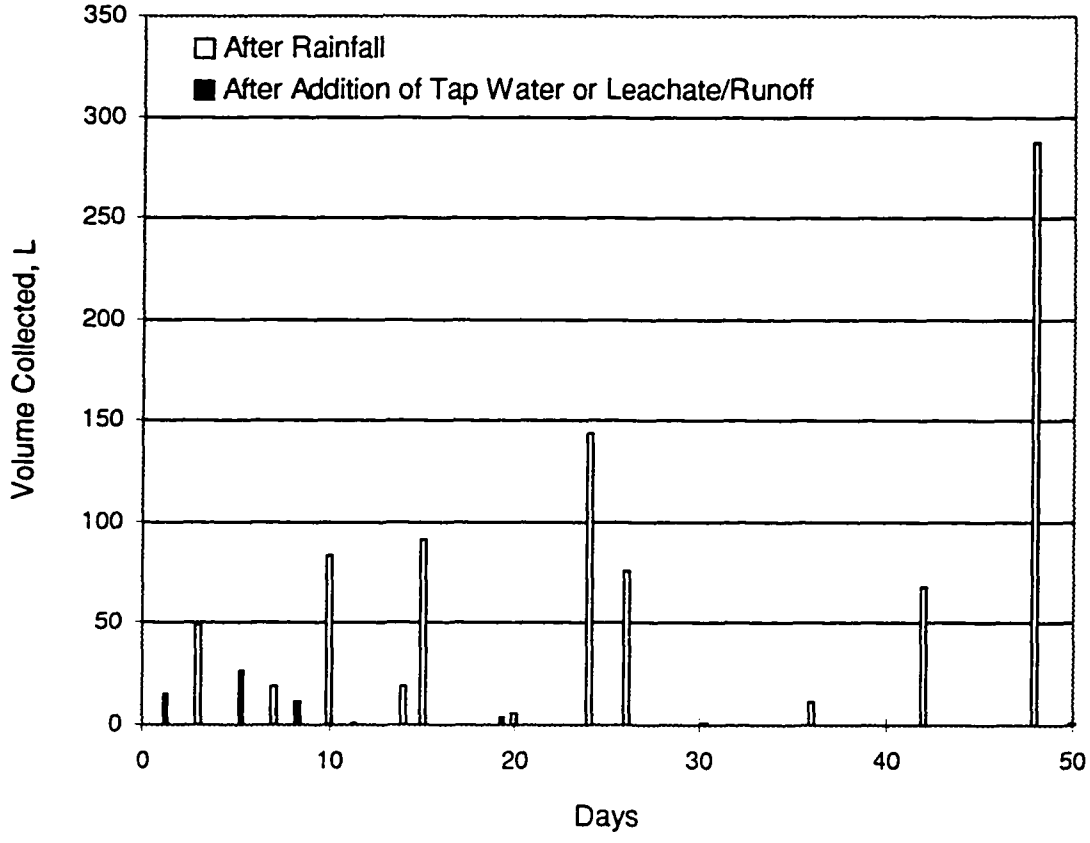



Figure 4.2. Volume of leachate/runoff collected after rainfall or watering events. Similar volumes were collected from all windrows after all events.

section at three locations along the windrow length. Compost samples were analyzed for moisture content, volatile solids, organic C, total N, $NO_3$, $NH_4$ and primary elements. Data reported for leachate/runoff and compost samples are the means of three samples.

## Measurements and Analytical Methods

Compost temperature was measured with copper-constantan thermocouples at four equally-spaced locations along the windrow length and connected to a datalogger (model CR7, Campell Scientific, Logan, UT). Percent oxygen in the compost airspace was measured three times weekly using a model OT-21 oxygen meter and probe (Demista Instruments, Wheeling, IL).

Compost moisture content was determined twice weekly by the gravimetric method (APHA et al., 1992). After drying, samples were ground to 150-mesh size, thoroughly mixed and stored in air-tight containers for further analysis. Approximately 5 g subsamples were combusted at 550 °C to determine volatile solids content. About 20 mg subsamples were used for organic C and total N determination using a Heraeus model CHN-O Rapid Analyzer. $NO_3$ and $NH_4$ concentrations in compost and leachate/runoff were determined using a Wescan model 360 Analyzer (Wescan Instrument Inc., Deerfield, IL). Leachate/runoff pH was measured in-situ with a Digi-Sense 5939-10 digital pH meter (Cole-Parmer Instrument Co., Niles, IL). Leachate/runoff COD was determined by the titrimetric method (APHA et al., 1992) using accu-TEST™ vials (Bioscience, Inc., Bethlehem, PA). Approximately 500 mg of ground compost were digested with 16 N nitric acid for elemental analysis.

Elemental analysis of compost extract and leachate/runoff were determined by the Inductively Coupled Plasma (ICP) method (APHA et al., 1992).

4.3 Results and Discussion

## Compost Characteristics

Moisture content remained in the desirable range (35-60%) during most of the composting process for the L and W windrows but not for the R windrow (Figure 4.3). Although the L and W windrows were frequently watered during the first two weeks, the maximum moisture content achieved during that period was only 42%. After turning on Day 17, moisture content consistently remained between 40-60%. Degradation of crawfish residuals apparently facilitated moisture retention by rice hulls. Although the moisture content for the R windrow was relatively low, this windrow maintained similar temperature profile to the others during most of the 50-d composting study (Figure 4.4). This is probably due to a greater heat capacity of the relatively drier R windrow. By the third day, all windrows had reached their highest temperature of 60°C. Shortly thereafter, temperature dropped to about 45°C. Temperature then declined gradually to near ambient (30°C) at about Day 40. This suggests that the self-heating phenomena had ceased and the available substrate had reduced.

During composting, the volatile solids content tends to decrease due to microbial degradation of organic matter and production of carbon dioxide. For the R and W windrows, the volatile solids content decreased gradually through the entire study period, as shown in Figure 4.5. The addition of leachate/runoff on Day 30 led to an increase in volatile solids in the L windrow reaching a mean final value of 66.0%,

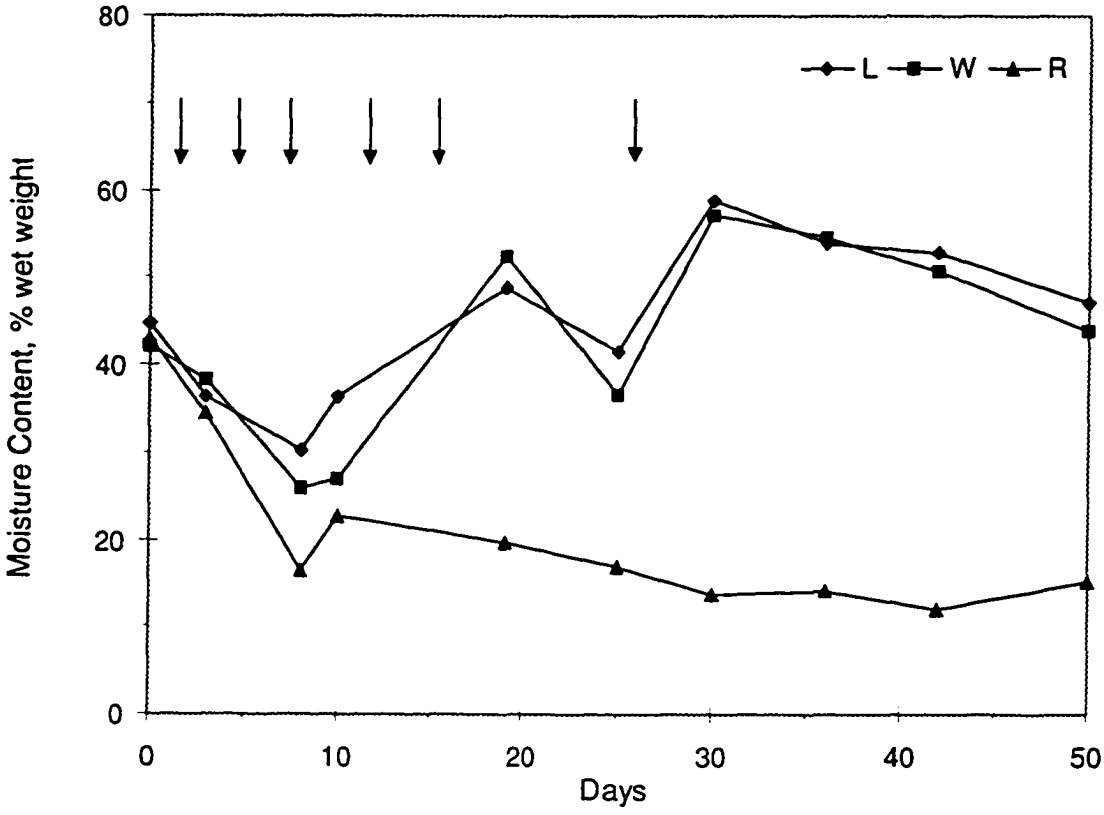



Figure 4.3. Moisture content of compost during the 50-d study period. Arrows represent the times when the leachate/runoff or tap water were added to moisten the L and W windrows. L = watered with leachate; W = watered with tap water; R = unwatered except for rainfall.

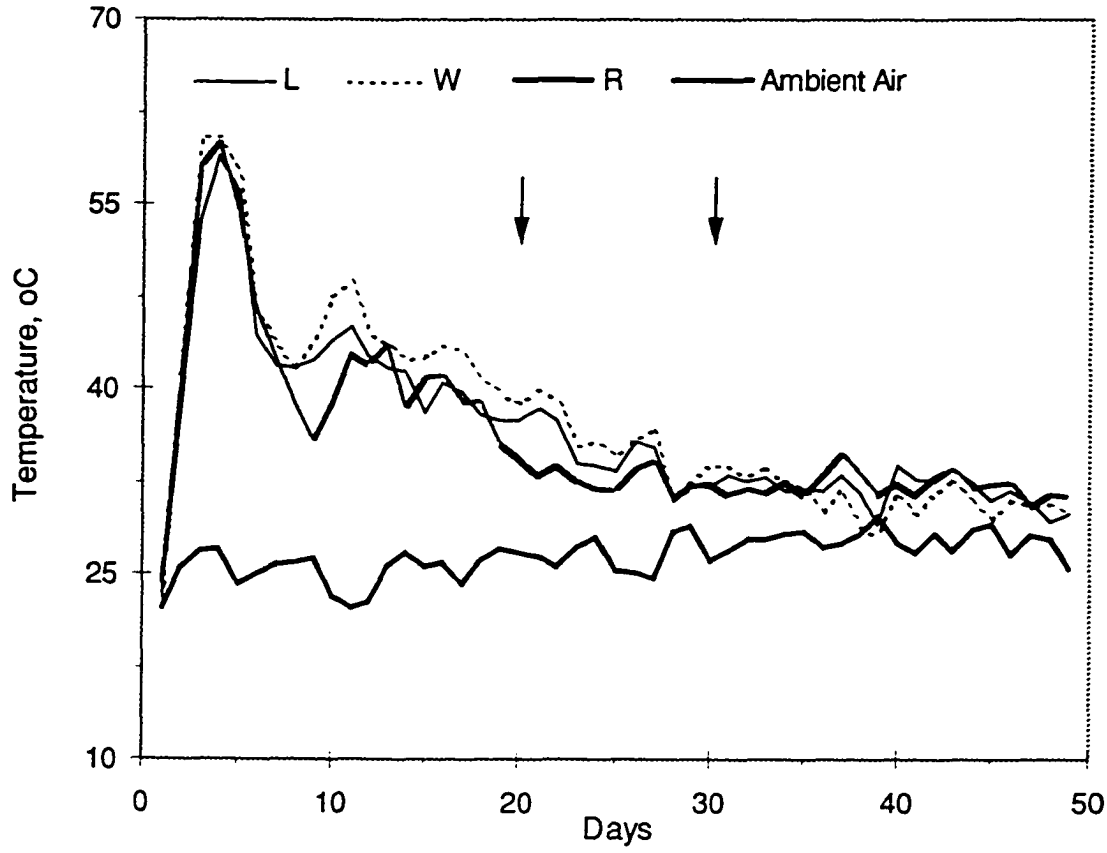



Figure 4.4. Mean compost and ambient air temperatures. Arrows represent the times when the windrows were turned. L = watered with leachate; W = watered with tap water; R = unwatered except for rainfall.

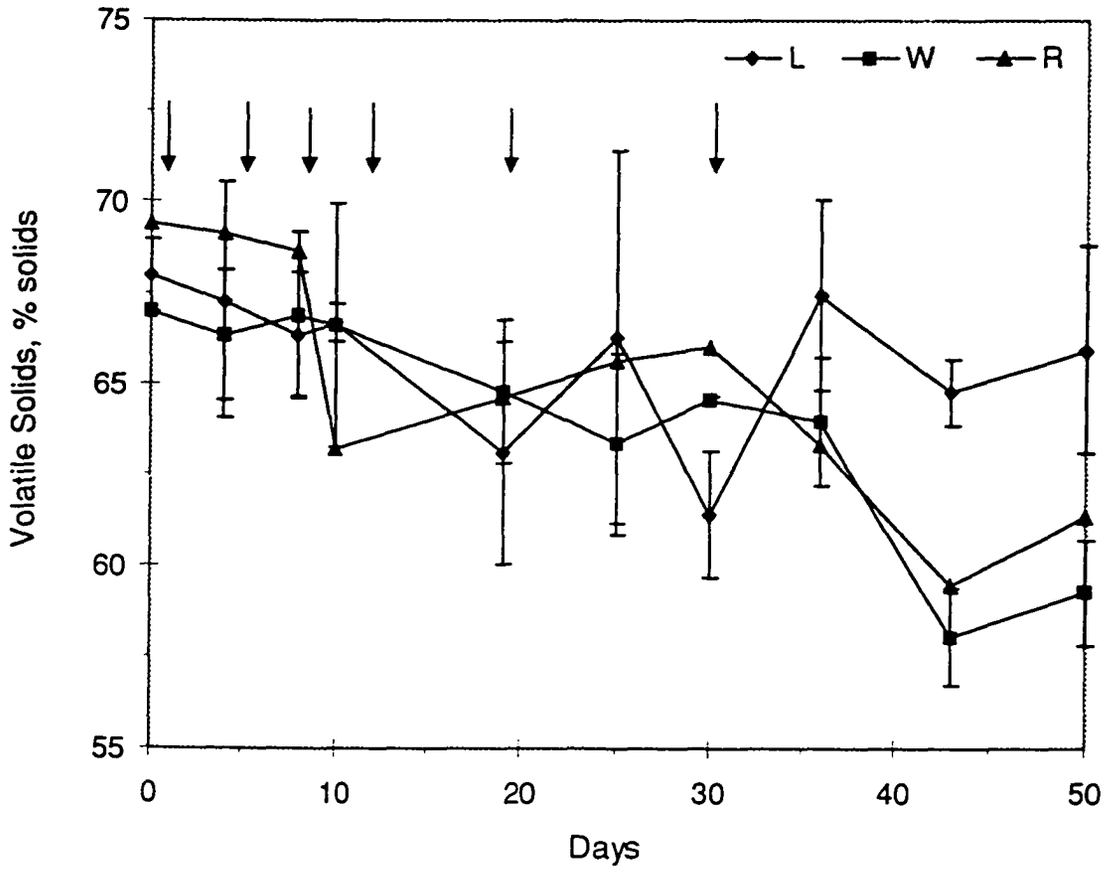



Figure 4.5. Change of volatile solids content of compost during the 50-d study period. Arrows represent the times when the leachate/runoff or tap water were added to moisten the L and W windrows. Error bars are the standard deviations. L = watered with leachate; W = watered with tap water; R = unwatered except for rainfall.

after 50 d of composting. This value was significantly higher than either the R (61.4%) or W (59.3%) windrow ($P=0.01$, $\alpha=0.05$). Because the leachate/runoff contains unstable organic matter, it is recommended that its reuse for moisture control be adopted only during the early period of high decomposition for batch composting. In this manner, the leachate/runoff can be metabolized by the composting organisms. The leachate/runoff may not contain enough energy substrate for microbial communities to heat up the windrow once the main substrate (i.e. crawfish residual) is consumed during the late stage of the composting process.

Organic C content of the composted material was reduced from an average initial value of about 394 g/kg to a final value of about 351, 348, and 362 g/kg for L, W, and R, respectively (Table 4.2). The R windrow had the smallest final C concentration simply because crawfish residuals were not completely degraded. Final C concentration for L was slightly higher than that of W since L received organic C contained in the leachate/runoff added to the windrow on day 30.

Total N was reduced from an initial value of 15.8 g N/kg to 9.2, 8.9, and 11.2 g N/kg for L, W and R windrows, respectively. Final total N was the highest for the R windrow since crawfish residuals were not completely degraded. For the same reason, the R windrow had very high final $NH_4$ concentration (330.4 mg $NH_4$-N /kg) and low final $NO_3$ concentration (47.4 mg $NO_3$-N/kg) compared to the L or W windrows at the end of the 50-d composting period. No significance difference was observed in the final total N, $NH_4$ and $NO_3$ concentrations between L and W windrows (Table 4.2). It appears that the addition of leachate/runoff to a composting mixture of rice hulls and

Table 4.2. Carbon, nitrogen, ammonium and nitrate concentrations, and C:N ratios in initial and final compost from three windrows under three water regimes^.

| Property | Units | Initial | Final | | | $LSD_{0.05}$* |
|---|---|---|---|---|---|---|
| | | | L | W | R | |
| Organic C | g/kg solids | 394.2 | 351.1 | 348.4 | 362.5 | 1.5 |
| Total N | g/kg solids | 15.8 | 9.2 | 8.9 | 11.2 | 0.4 |
| C:N | - | 24.9 | 38.2 | 39.1 | 32.4 | 11 |
| $NH_4$-N | mg/kg solids | 280.6 | 43.4 | 48.4 | 330.4 | 54 |
| $NO_3$-N | mg/kg solids | 34.2 | 156.7 | 156.8 | 47.4 | 23 |

^ L = Watered with leachate; W = Watered with tap water; R = Unwatered except for rainfall; Values are means of triplicate samples

* Least significance difference

crawfish residuals does not result in an increase in final compost total N, $NH_4$, or $NO_3$ concentrations in comparison to the addition of tap water.

During composting, organic materials undergo mineralization and transformation into a more stable product by the action of microorganisms. Organic as well as inorganic compounds are consumed by microorganisms. Inorganics are usually considered a minor source of nutrients for microorganisms. During organic material degradation, inorganics are released from their complex form and could be subject to losses (Rymshaw et al., 1992). Because of the reduction in the mass of organic compounds during composting, element concentration per dry weight may increase or remain the same if no actual losses by leachate and runoff occur. In this experiment, compost Mg, Mn, Na, Ca, K, P and S concentrations on dry weight basis did not significantly change for either L, W, or R windrow from their initial concentrations (Table 4.3). This is probably due to the organic mass loss by leaching and mineralization, which was accompanied by the loss of elements by leaching. By expressing the element concentration on an ash weight basis (free of organic matter), all final elements concentrations were slightly higher for the L windrow than either the W or R windrow (Table 4.4). This trend was not strongly significant at $\alpha$=0.05. Therefore, the addition of leachate/runoff to an active compost pile does not strongly suggest an increase in the nutrient concentration of the compost product. However, this practice can mitigate the impact of composting operations from excessive nutrients, minerals, organics, and heavy metals loading into surface and ground waters.

Table 4.3. Initial and final concentrations of principal nutrients in mg/kg solids for the three windrows^.

| Element | Initial | Final | | | $LSD_{0.05}$* |
|---|---|---|---|---|---|
| | | L | W | R | |
| Mg | 785 | 946 | 945 | 972 | 221 |
| Mn | 241 | 254 | 283 | 237 | 38 |
| Na | 1,292 | 1,444 | 1,448 | 1,476 | 329 |
| Ca | 32,148 | 42,130 | 44,279 | 47,406 | 4,619 |
| K | 2,981 | 3,053 | 2,709 | 2,945 | 189 |
| P | 2,187 | 2,431 | 2,501 | 2,662 | 802 |
| S | 1,484 | 1,352 | 1,348 | 1,442 | 287 |

^ L = Watered with leachate; W = Watered with tap water; R = Unwatered except for rainfall; Values are means of triplicate samples

* Least significance difference

Table 4.4. Initial and final concentrations of principal nutrients in mg/kg ash for the three windrows^.

| Element | Initial | Final | | | $LSD_{0.05}$* |
|---|---|---|---|---|---|
| | | L | W | R | |
| Mg | 23.6 | 28.4 | 23.3 | 25.1 | 7.6 |
| Mn | 7.2 | 7.6 | 7.0 | 6.1 | 1.3 |
| Na | 38.8 | 43.3 | 35.7 | 38.1 | 11 |
| Ca | 963 | 1,270 | 1,088 | 1,219 | 527 |
| K | 89.7 | 91.7 | 66.9 | 76.3 | 20 |
| P | 65.6 | 73.2 | 61.5 | 68.6 | 24 |
| S | 44.6 | 40.6 | 33.2 | 37.2 | 10 |

^ L = Watered with leachate; W = Watered with tap water; R = Unwatered except for rainfall; Values are means of triplicate samples

* Least significance difference

## Leachate/runoff Characteristics

For all windrows, leachate/runoff had a rapid pH increase from near neutral pH (6.8) on the first day to alkaline pH (9.2) on day 5 (Figure 4.6). This initial rapid pH increase is probably due to ammonification and its role as a proton sink (Miller, 1992). The pH then fluctuated between 8 and 9 for the next 10 days. For the rest of the period, pH varied between 7 and 8, however, the R windrow maintained higher pH probably due to its continuous generation of $NH_3$. At the end of 50-d composting period, pH was about 7.2 for L and W windrows, and 7.5 for R windrow.

In general, the amount of rainfall or water added to a windrow will have a direct effect on the amount of nutrient losses. Nutrient losses are attributed also to the nutrient concentration in the compost mixture and its availability to leaching. Daily nutrient concentration in leachate/runoff and daily leachate/runoff volume, following a rainfall or watering event, were used to determine nutrient losses from the windrow.

Ammonium losses in leachate/runoff were elevated, especially during the first 25 days where degradation and mineralization rates are at maximum (Figure 4.7). Ammonium loss totaled about 22 g $NH_4$-N/kg N (347 mg $NH_4$-N/kg solids) of the original mixture from the W windrow over the 50-d period. During the highly active period, the readily available substrate and the favorably composting conditions initiated $NH_4$ generation resulting from the rapid ammonification of organic nitrogenous compounds. Ammonium losses were reduced from 4.4 g $NH_4$-N/kg N on day 15 to 1.3 and 0.1 g $NH_4$-N/kg N on days 26 and 42,

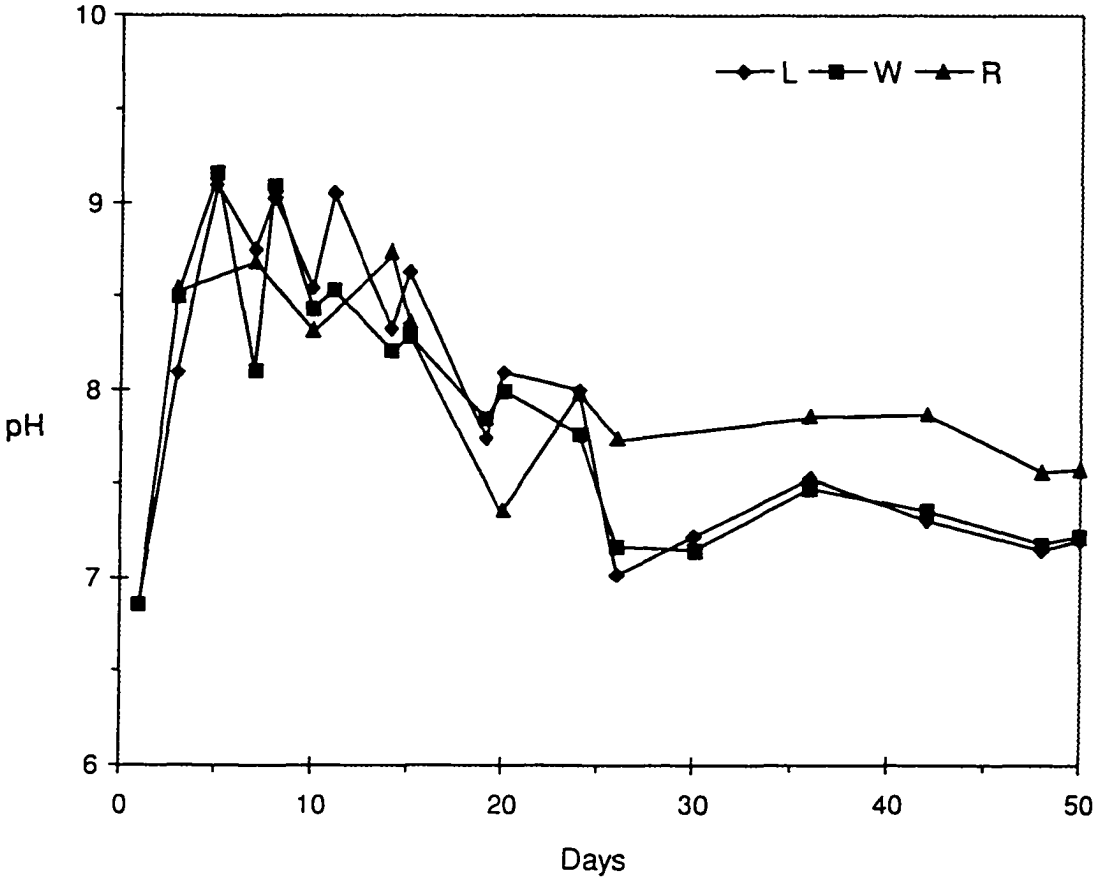



Figure 4.6. Leachate/runoff pH from the L, W, and R windrows during the 50-d study period. L = watered with leachate; W = watered with tap water; R = unwatered except for rainfall.

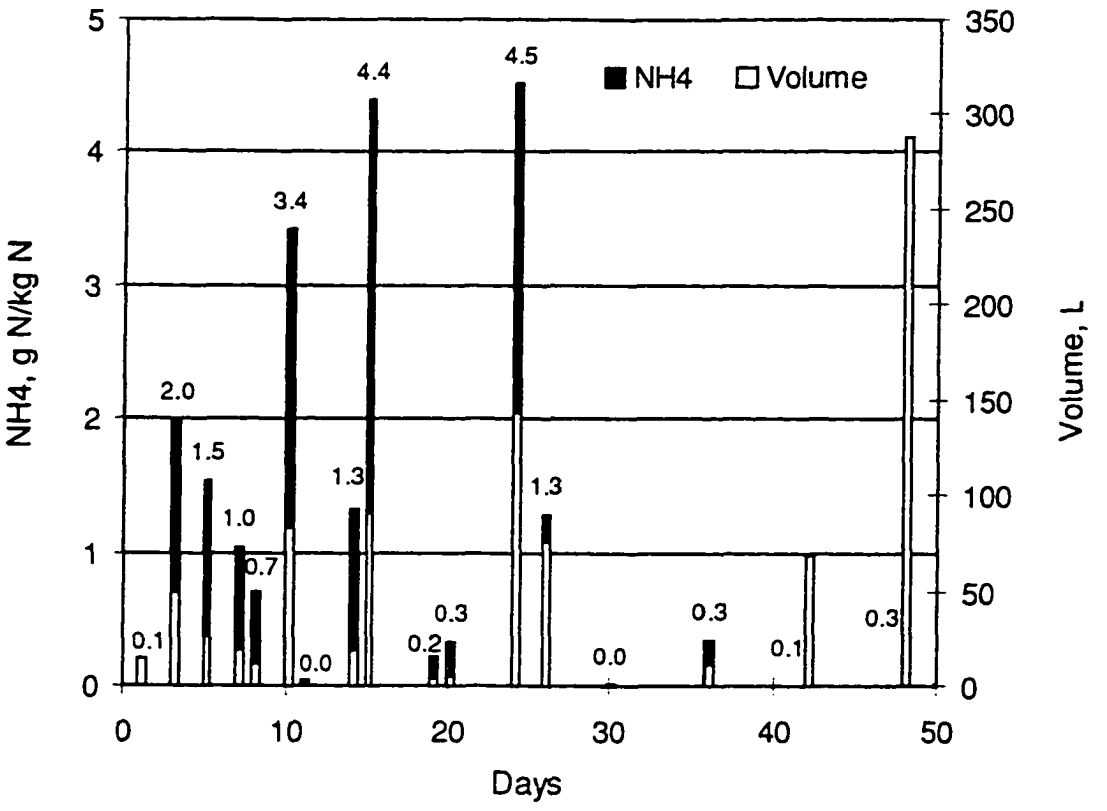



Figure 4.7. Ammonium losses in leachate/runoff from the windrow watered by tap water expressed in g per kg total N of the initial compost dry mass.

respectively, where leachate/runoff volumes collected on these three days were comparable (around 80 L). For the W windrow, ammonium concentration peaked at 190.6 mg $NH_4$-N/L on day 14 when leachate/runoff volume was 18.9 L, and it reached a minimum value (0.43 mg $NH_4$-N/L) on day 50 although leachate/runoff volume was only 0.2 L (Table 4.5). A typical $NH_4$ concentration range in municipal effluent is between 12 and 50 mg/L (Rymshaw et al., 1992).

Nitrate losses were fairly distributed for the W windrow over the 50-d period (Figure 4.8). Nitrate is highly soluble and is easily leached by water from the compost windrow. Nitrate total losses amounted to 2.23 g $NO_3$-N/kg N (35.8 mg $NO_3$-N/kg solids) for the W windrow. Nitrate losses were lower than ammonium losses presumably due to the lower rate of nitrification compared to the rate of ammonification. Nitrate losses in leachate/runoff peaked at day 24, resulting from the 143.8 L leachate/runoff volume collected from rainfall and amounted to 0.46 g $NO_3$-N/kg N. Nitrate maximum concentrations of 38.8 and 23.5 mg $NO_3$-N/L for the W and R windrows, respectively, were reached on day 36, when volume collected was 11.3 L (Table 4.5). Ballestero and Douglas (1996) determined that horse-bedding compost lost 230 g total N/kg of compost initially present over a 60-d study period, which is much higher than the total amount of $NH_4$ and $NO_3$ lost in this experiment. Ulén (1993) found that an average of 48.8 g total N/kg N initially present were leached over a seven-month winter experiment from straw and manure compost.

Table 4.5. Leachate/runoff minimum and maximum concentrations in mg/L of selected properties for the W and R windrows^.

| Property | W | | | | R | | | |
|---|---|---|---|---|---|---|---|---|
| | Minimum | Day | Maximum | Day | Minimum | Day | Maximum | Day |
| COD | 307 | 48 | 4,587 | 19 | 441 | 50 | 3,980 | 7 |
| $NH_4$ | 0.43 | 50 | 190.6 | 14 | 5.68 | 50 | 183.5 | 14 |
| $NO_3$ | <0.05 | 7 | 38.8 | 36 | <0.05 | 10 | 23.5 | 36 |
| Mg | 1.84 | 10 | 69.8 | 36 | 1.72 | 10 | 22.5 | 36 |
| Mn | 0.05 | 50 | 3.11 | 19 | 0.32 | 50 | 2.29 | 36 |
| Na | 22.3 | 3 | 535.8 | 36 | 8.90 | 3 | 207.0 | 36 |
| Ca | 4.45 | 10 | 399.8 | 36 | 3.83 | 10 | 59.5 | 36 |
| K | 33.6 | 7 | 1,027 | 36 | 64.5 | 10 | 434.1 | 36 |
| P | 2.30 | 50 | 46.6 | 19 | 8.50 | 50 | 46.2 | 36 |
| S | 11.0 | 48 | 146.5 | 36 | 9.60 | 48 | 62.4 | 36 |

^ W = Watered with tap water; R = Unwatered except for rainfall; Concentrations are in mg/L

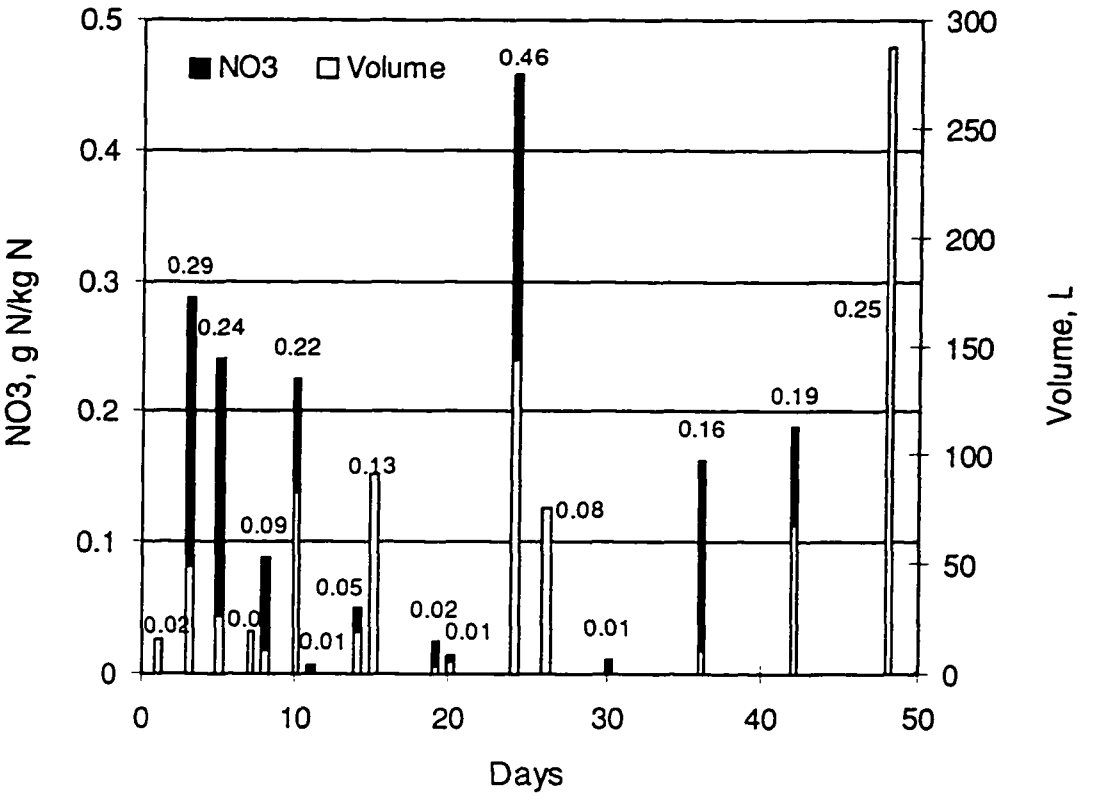



Figure 4.8. Nitrate losses in leachate/runoff from the windrow watered by tap water expressed in g per kg total N of the initial compost dry mass.

Phosphorous is the limiting nutrient causing eutrification in surface water from land runoff, therefore it is important to document phosphorous losses from composting operations. Phosphorus losses from the W windrow were peaked on day 24 and they amounted to 14.1 mg P/mg solids (Figure 4.9). Most of the soluble-P was leached during the first 25 days. Phosphorus losses were reduced from 8.5 mg P/mg solids on day 15 to 4.8 and 2.3 g mg P/mg solids on days 26 and 42, respectively, where volumes collected on these three days were comparable (around 80 L). Over the 50-d period, total soluble-P losses were 59.5 mg P/kg solids. Maximum P concentration of 46.6 mg P/L was reached on day 19 for the W windrow, where total volume collected was 3.8 L. Typical phosphate concentration range in municipal effluent is between 6-20 mg/L (Rymshaw et al., 1992). Ulén (1993) observed a mean loss of 24 g P/kg P in winter compost leachate and a typical total-P concentration of 50 mg/L in runoff from straw and manure compost.

Organic C is mainly released during the early stages of composting processes when the organic substrate is highly subject to degradation by microorganisms. Chemical oxygen demand (COD) in leachate/runoff was measured to estimate organic C losses. In this experiment, COD loading was mainly during the first 25 d for the W windrow (Figure 4.10). The COD losses were reduced from 1.6 to 1.3 g COD/kg C from day 24 to day 48, in which the volume collected was doubled on the latter day. This shows that COD concentration was reduced over a half from day 24 to day 48. Maximum COD concentrations of 4,587 and 3,980 mg/L were reached on day 19 and day 7, for the W and R windrows, respectively (Table 4.5). Total COD loading over

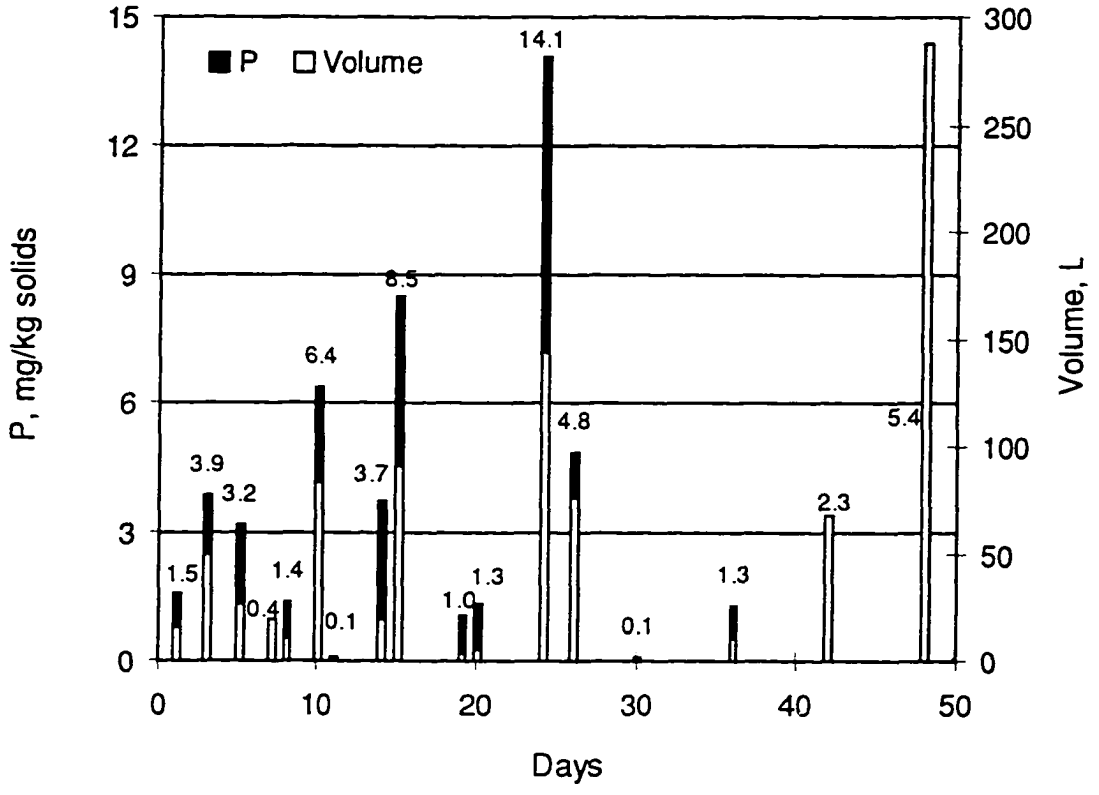



Figure 4.9. Phosphorus losses in leachate/runoff from the windrow watered by tap water expressed in g per kg of the initial compost dry mass.

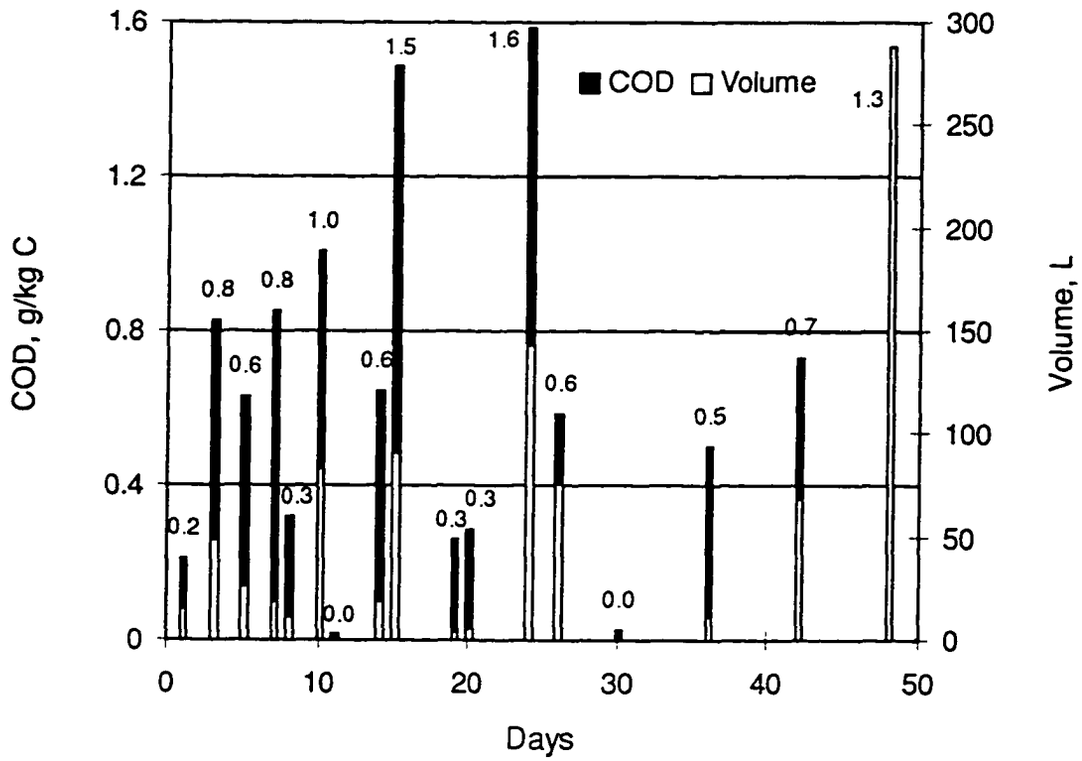



Figure 4.10. Organic carbon losses in leachate/runoff from the windrow watered by tap water expressed as chemical oxygen demand (COD) in g per kg C of the initial compost dry mass.

the 50-d period was 11.2 g COD/kg C (4.4 g COD/kg solids) from the W windrow. The COD concentrations observed here are comparable to COD values from runoff of an open dairy lot, which range from 2,300 to 5,000 mg/L (Sweeten and Wolfe, 1990).

## 4.4 Conclusions

During composting crawfish residuals and rice hulls, excessive amounts of nutrient were released through leaching and runoff. Movement of these nutrients could have a detrimental effect on surface and ground waters quality if not properly managed. Organic C and $NH_4$ are mainly leached in the early phase of the composting process during high decomposition rate of organic substrate. The release of nitrate and other elements in leachate and runoff results from the mineralization process of organic compounds. Attenuation of nutrient losses in leachate and runoff occurs toward the end of the composting process.

The use of leachate/runoff on active compost may reduce the amount of nutrient losses in comparison to the addition of tap water. This treatment option would save fresh water need for compost piles or relying on rainfall while reducing the leachate and runoff amounts that may undergo conventional treatment methods. The addition of leachate/runoff needs to be adopted only during the high microbial activity period to allow for the assimilation of its organic content.

Compost nutrient retention from the application of leachate/runoff to active compost consisting of different feedstock merits further investigation. Further research is needed to characterize the leachate and runoff in various composting

environments and weather conditions. Characterizing the leachate and runoff can provide valuable information for better design of compost facilities.

## 4.5 References

American Public Health Association (APHA), American Water Works Association, and Water Pollution Control Federation. 1992. Standard methods for the examination of water and wastewater. 18th edition. APHA, Washington, D.C.

Andree, S. 1991. Implementing fisheries by-products composting applications: the next step. In: Proceedings of the 1991 Fisheries By-Products Composting Conference, UW Sea Grant Institute, Madison, WI. pp. 181-187.

Ballestero, T. P. and E. M. Douglas. 1996. Comparison between the nitrogen fluxes from composting farm wastes and composting yard wastes. Transactions of the ASAE, 39(5): 1709-1715.

Brinton, W. F. and M. D. Seekins. 1988. Composting fish by-products: A feasibility study. Time & Tide, RC &D, Mid-Coast Compost Consortium, Waldodoro, Maine.

Frederick, L., R. Harris, L. Peterson, and S. Kehrmeyer. 1989. The compost solution to dockside fish wastes. Universitory of Wisconsin Sea Grant Advisory Services, Madison, WI. WIS-SG-89-434.

Kovacic, D. A., R. A. Cahill, and T. J. Bicki. 1992. Compost: Brown gold or toxic trouble? Environmental Science and Technology, 26(1)38-41.

Miller, F. C. 1992. Composting as a process based on the control of ecologically selective factors. In: *Soil Microbial Ecology* by F. B. Metting Jr., (ed.), Marcel Dekker, New York, p. 514-544.

Rymshaw, E., M. F. Walter, and T. L. Richard. 1992. Agricultural composting: Environmental monitoring and management practices. Department of Agricultural Engineering, Cornell University, Ithaca, NY.

Spencer, R. 1991. Leachate management at a composting facility. Biocycle, 32(10)38-39.

Sweeten, J. M. 1990. Feedlot runoff characteristics for land application. In: the Proceedings of the Sixth International Symposium on Agricultural and Food Processing Waste, ASAE, St. Joseph, MI. pp. 168-184.

Ulén, B. 1993. Losses of nutrients through leaching and surface runoff from manure-containing composts. Biological Agriculture and Horticulture, 10:29-37.

# CHAPTER 5

# BIODEGREDABILITY, NUTRIENT ANALYSIS, AND MICROBIAL ACTIVITY DURING REPETITIVE ADDITION OF CRAWFISH RESIDUALS TO RICE HULL-CRAWFISH COMPOST

## 5.1 Introduction

Processing by-products from fish and seafood-related industries are highly organic and are typically rich in nitrogen (N) and readily-degradable organic carbon (C) compounds. These materials begin to decompose very soon after processing. Consequently, they become highly putrescent and could potentially create environmental problems if not handled and disposed of properly. By contrast, certain agro-industrial by-products are rich in less-readily-degradable C compounds, particularly lignocellulose (Shuler, 1980). Examples are rice hulls, bagasse, bark, and yard wastes. The high lignin content of these and other materials causes them to degrade slowly under normal conditions (Crawford, 1976).

Fish processing by-products are generally high in N and low in C thus providing a low C:N ratio (Table 5.1). These materials may cause odor problems during composting through the production of ammonia and other nitrogenous and organic compounds. Properly co-composting fish by-products with agro-industrial by-products, would transform these by-products into valuable resources.

Once the readily-available C and available N are consumed during composting, the decomposition rate will slow (Garcia, 1991; Regan and Jeris, 1970). In earlier experiments with crawfish processing residuals and rice hulls (chapter 3), results demonstrated that most, if not all, composting was attributed to the degradation of the

Table 5.1. Examples of nitrogen and carbon content of selected fishery and agro-industrial processing residuals.

| Material | N (g/kg) | C (g/kg) | C:N |
|---|---|---|---|
| Crawfish | 50.3 | 317 | 6.3 |
| Fish | 48.8 | 177 | 3.6 |
| Shrimp^ | 95.1 | 323 | 3.4 |
| Crab & lobster^ | 61.2 | 299 | 4.9 |
| Wood chips | 2.29 | 476 | 208 |
| Rice hulls | 4.84 | 372 | 77 |
| Bagasse | 9.28 | 436 | 47 |
| Hardwood Bark | 10.7 | 443 | 41 |

^ Rynk, 1992.

experiments with crawfish processing residuals and rice hulls (chapter 3), results demonstrated that most, if not all, composting was attributed to the degradation of the crawfish residuals since rice hulls contain more than 60 % lignocellulose and 20 % silica on a dry weight basis (Mizuki et al., 1993). They also contain low concentrations of macronutrients (N, P, and K) and micronutrients. These properties make rice hulls less susceptible to attack by microbes and consequently degrade very slowly. Having a high C:N ratio, rice hulls must be combined with materials high in N to increase the rate of degradation. The slow degradation rate of rice hulls allows them to be reused as bulking material by simply adding raw crawfish residuals to the previously composted rice hull-crawfish residual compost. A cost saving in bulk materials is thus realized by reusing the rice hulls.

When designing any compost process, knowledge of compost feedstock degradability is essential (Haug, 1993). In this study, dry mass and organic matter losses during composting were estimated in order to assess the degradability of different rice hull/crawfish residual compost mixtures. Nitrogen losses and final compost characteristics were also analyzed in order to asses the nutrient value (N, P, K) of the completed compost mixture.

Specific $O_2$ uptake rate (SOUR) and $CO_2$ production are considered key indicators of microbial activity. As organic carbon is degraded, $O_2$ is consumed and $CO_2$ is produced. When the organic substrate becomes limited, $O_2$ consumption and $CO_2$ production are reduced. Compost is stable once organic matter resists further degradation. The method of determining the rate of $CO_2$ production is often used to indicate compost stability or "end point" (Feldman, 1995). Usually, when the $CO_2$

production rate reaches steady state below 5 mg $CO_2$-C/g C/day, the compost process is considered stable (Feldman, 1995). In this study, $O_2$ consumption and $CO_2$ production rates were estimated and compared for different rice hull/crawfish residual compost mixtures.

The objectives of this chapter were to characterize and compare the degradation rates, microbial activity, and nutrient values of rice hull/crawfish residual compost mixtures and to examine the efficacy of adding raw crawfish residuals to partially composted rice hulls. More specifically, the objectives were to 1) determine dry mass and organic matter losses, 2) measure nitrogen loss, 3) quantify $O_2$ consumption and $CO_2$ production, during composting, and 4) estimate nutrient values of the final compost.

## 5.2 Materials and Methods

### Experimental Design

Crawfish residuals were composted with rice hulls in 3-L beakers containing about 600 g of mixed material. Crawfish residuals were ground (5 mm) before mixing with rice hulls. Three replicates of four different mixing ratios of crawfish residuals and rice hulls, were used to obtain initial C:N ratios of 14:1, 17:1, 25:1 and 42:1. The initial C: N ratio is used as the treatment in a 3x4 factorial experimental design. The 12 reactors were placed in an environmental chamber (Lab-Line Instruments, Melrose Park, IL) having the capacity to control temperature between 25 and 70 °C.

Three separate runs were performed. A new batch of crawfish residuals was added to the finished product of the first run identified as phase I. This second

compost process was identified as phase II. As the degradation rate of phase II slowed, raw crawfish residuals were again added to begin phase III.

### Sampling and Measurement Procedure

Samples were taken once weekly from each reactor to determine moisture, volatile solids, organic-C,and total-N concentrations. Carbon dioxide production rate was continuously monitored and SOUR was estimated 2-3 times weekly. Water was added when necessary to maintain optimum moisture conditions in all reactors (40-65% wet basis). The compost was turned manually 3-4 times weekly to homogenize the mixture. Compost percent oxygen concentrations were measured four times weekly to confirm aerobic conditions.

Moisture content was determined gravimetricly at 60°C (APHA et al., 1992). After drying, samples were ground to 150-mesh size, thoroughly mixed and stored in air-tight containers for further analysis. Approximately 3 g subsamples were combusted at 550 °C to determine volatile solids content. About 20 mg subsamples were used for organic C and total N determination using a Heraeus model CHN-O Rapid Analyzer. Elemental analysis of compost extract was determined for the final product by the Inductively Coupled Plasma (ICP) method (APHA et al., 1992). Percent oxygen in the compost air space was measured using a model OT-21 oxygen probe (Demista Instruments, Wheeling, IL).

A simplified version of the procedure described by Iannotti et al. (1993) was used to measure oxygen consumption. Oxygen consumption rate was measured by placing an active compost sample (~ 3 g) in a sealed 220-ml screw-top jar filled completely with dionized water. The solution was aerated for 10 seconds. The jar

was then placed in a water bath maintained at about 45 °C to measure dissolved oxygen (DO) using a stirring bar oxygen probe (YSI 5905) connected to a DO meter (YSI 5100) (YSI Incorporated, Yellow Springs, OH). Dissolved oxygen readings were recorded every minute for 10 minutes.

Carbon dioxide production was measured by incubating about 15 g of active compost in sealed screw-jar (300 ml) in the control chamber for about 64 hours at a time throughout each phase of the experiment. A gas chromatograph model MT-150G (Tractor, Austin, TX) was used to measure the $CO_2$ concentration in the jar headspace.

**Determination of Organic Mass, Dry Mass, and N Losses**

(1) Organic Mass Degradation and Dry Mass Loss

Degradation of organic matter is generally determined by a mass balance ofthe input and output materials. The mass lost during the process represents the total degradation. Dry mass degradability was determined to compare the degradability of rice hull-crawfish residual compost during the three different phases of the experiment. Measuring total mass during the composting process is not always practical and cost effective due to handling of different feedstock and the large volume produced. However, measurement of volatile solids concentration is feasible and a common practice, since aerobic biological activity decreases the volatile solids content by converting organic C to $CO_2$. Volatile solids concentration during composting is then used to estimate organic matter degradation. According to the conservation of ash, organic matter degradation is expressed as (Haug, 1993):

$$K_{OM} = \frac{VS_i - VS_f}{VS_i} 100 = \frac{(\%VS_i - \%VS_f)100}{\%VS_i(100 - VS_f)} 100 \qquad (5.1)$$

where,

$K_{OM}$ = total organic matter degradation, %

$VS_i$ and $\%VS_i$ = initial volatile solids content (g) and concentration (%)

$VS_f$ and $\%VS_f$ = final volatile solids content (g) and concentration (%).

Total dry mass degradation ($K_{dm}$) is calculated as a function of $K_{OM}$ as follows:

$$K_{dm} = \frac{dm_i - dm_f}{dm_i} 100 = \frac{(VS_i + Ash_i) - (VS_f + Ash_f)}{dm_i} 100 \qquad (5.2)$$

where,

$dm_i$ = initial dry mass, g

$dm_f$ = final dry mass, g

$Ash_i$ = initial ash mass, g

$Ash_f$ = final ash mass, g.

Because of conservation of ash, $Ash_i = Ash_f$.

Also, since,

$$dm_i = \frac{VS_i}{\%VS_i} 100$$

it follows that,

$$K_{dm} = \frac{(VS_i - VS_f)}{\frac{VS_i}{\%VS_i} 100} 100 = \frac{K_{OM}(\%VS_i)}{100} \qquad (5.3)$$

Organic matter or dry mass degradation can be obtained at any time during the composting period once the volatile solids concentration is known. Also, dry mass can be back-calculated at any time during the composting period by the relation:

$$dm(t) = \frac{[100 - K_{dm}(t)]}{100} dm_i \qquad (5.4)$$

where,

dm(t) = dry mass, g, at any time (t)

$K_{dm}(t)$ = dry mass degradation, %, at any time (t).

(2) Nitrogen Losses

A N mass balance is used to determine nutrient loss during and after the composting process. For example, knowing the total N concentration after a time t of composting, total N losses are found by:

$$m_N(t) = [C_N(t)][dm_i - dm(t)] \quad (5.5)$$

where,

$m_N(t)$ = total N losses, mg

$C_N(t)$ = total N concentration (mg N/g dry mass).

**Determination of Specific Oxygen Uptake and $CO_2$ Evolution Rates**

(1) Specific Oxygen Uptake Rate

Specific oxygen consumption or uptake rate (SOUR) was calculated from the change of DO over time per g volatile solids [(mg $O_2$/g VS)/hr] by the following:

$$SOUR = \frac{dDO}{dt}\frac{V}{VS} = \frac{dDO}{dt} = \frac{100V}{m(\%VS)} \quad (5.6)$$

where,

$\frac{dDO}{dt}$ = slope of the fitted curve of the dissolved oxygen (mg/L) versus time (hour)

V = water volume, L

VS = volatile solids content, g

m = dry mass of compost sample, g

%VS = percentage of VS in m, %.

(2) $CO_2$ Evolution Rate

The amount of $CO_2$ evolved during the incubation period was computed:

$$r_{CO2} = \left( \frac{V}{22.4} \frac{M_C(\%C)}{m} (\%CO_2 - \text{blank}) \right) / \Delta t \qquad (5.7)$$

where,

$r_{CO2}$ = $CO_2$ evolution rate, $\left( \frac{mg(CO_2 - C)}{gC} \right)$/day

V = volume of jar, L

% $CO_2$ = $CO_2$ concentration in jar (%) trapped over time, $\Delta t$ (day)

blank = blank sample $CO_2$ concentration, %

Mc = molecular mass of C, g

m = dry mass of compost sample in jar, g

%C = carbon concentration in m, %

and where, 22.4 L/mole is the standard molar volume constant.

5.3 Results and Discussion

**Temperature, Moisture Content, and Percent Oxygen**

By adjusting the temperature in the control chamber, temperature scheme in the reactors was simulated to the observed temperature profile of the batch mixture of rice hulls and crawfish residuals during an earlier experiment (Chapter 3, Figure 3.2). Temperature was maintained in the thermophilic range (45-60°C) during the first 10 days and upper mesophilic range (35-45°C) during the following 10 days, and lower mesophilic range (25-35°C) thereafter (Appendix B: figures B.1, B.2, and B.3). Temperatures of different reactors at one time were within 8°C during most of the period for all three phases of the experiment.

Percent oxygen in compost air space describes whether aerobic condition is pronounced. Oxygen concentration below 5% inhibits aerobic microorganisms while promoting anaerobes. It is recommended that the oxygen concentration remains above 5% during decomposition (Rynk, 1992). Oxygen concentrations were maintained well above 5% for most of the reactors except for four reactors during the first day of phase I of the experiment (Appendix B: figures B.4, B.5, and B.6). Manually mixing and exposing to air the materials in the reactors provided aerobic conditions.

Moisture content was maintained in the desirable range (45-60%) for all reactors during the three phases of the composting process (Appendix B: figures B.7, B.8, and B.9). Moisture control is necessary to replenish water loss from drying and to assure optimum moisture content for microbial activities.

### Changes in Organic Matter (Volatile Solids) and Total Dry Mass

During all three phases of the experiment, volatile solids content was reduced with the advancement of the biochemical reaction. Initial mixtures having a higher C:N ratio tended to have higher volatile solids content as well. Initial volatile solids contents of 68.4, 72.6, 76.2, and 80.9 %, were obtained from mixtures having initial C:N ratios of 14, 17, 25, and 42, respectively. Raw rice hulls and crawfish residuals have volatile solids content of 81.3 and 62.1 %, respectively. During phase I, volatile solids content decreased to values of 63.0, 69.3, 73.5, and 79.3 % for the CN 14, CN 17, CN 25, and CN 42 treatments, respectively, by the end of the 40-day period (Figure 5.1).

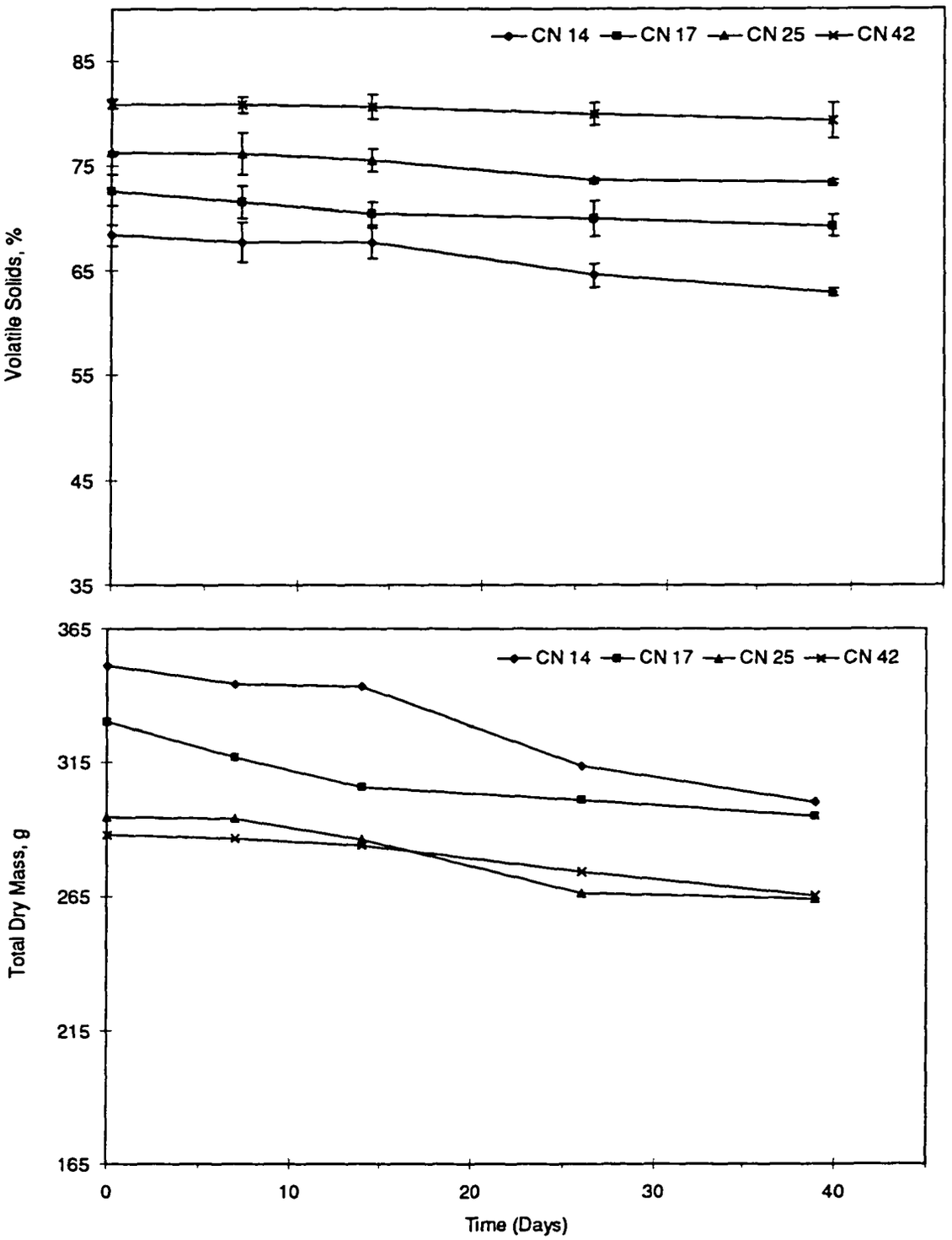



Figure 5.1. Volatile solids concentration (%) and total dry mass (g) versus time (Days) for the four treatments during phase I. Data are means of triplicate samples.

Phase II was initiated by recycling the product of phase I with a batch of crawfish residuals. Crawfish residuals were added at different amounts to each of the earlier treatments to obtain C:N ratios of : 11, 13, 15, and 20 and initial volatile solids content of 60.3, 64.1, 70.4, and 72.9 %, respectively. During phase II, volatile solids in the reactors were continuously decreasing to values of 50.2, 55.5, 65.7 and 67.9 %, for CN 11, CN 13, CN 15, and CN 20 treatments, respectively, at the end of the 40-day period (Figure 5.2).

Phase III was initiated by recycling the product of phase II with a new batch of crawfish residuals. Initial C:N ratios became as follow: 21, 20, 17, and 18 and initial volatile solids contents were 52.9, 55.2, 59.9, and 62.1 %, respectively. In this phase, although all four treatments had relatively similar initial C:N ratios, their initial volatile solids contents were significantly different (P=2.6E-06, $\alpha$=0.05) (Appendix A: Table A.5). Volatile solids in the reactors continuously decreased and they reached values of 38.7, 40.0, 49.5 and 51.2 %, for CN 21, CN 20, CN 17, and CN 18 treatments, respectively, at the end of the experiment (Figure 5.3).

Total dry mass for phase I had a different trend than for phase II and III (figures 5.1, 5.2, and 5.3). In phase II and III, total dry mass experienced a sharp decline as commonly observed during the early stages of composting. This decline meant that substrate was readily available for microbial consumption. For phase I, acclimation of microbial population to the newly mixed feedstock delayed this phenomena. Total dry mass reached a steady state toward the end of each phase implying that the exhaustion of the substrate.

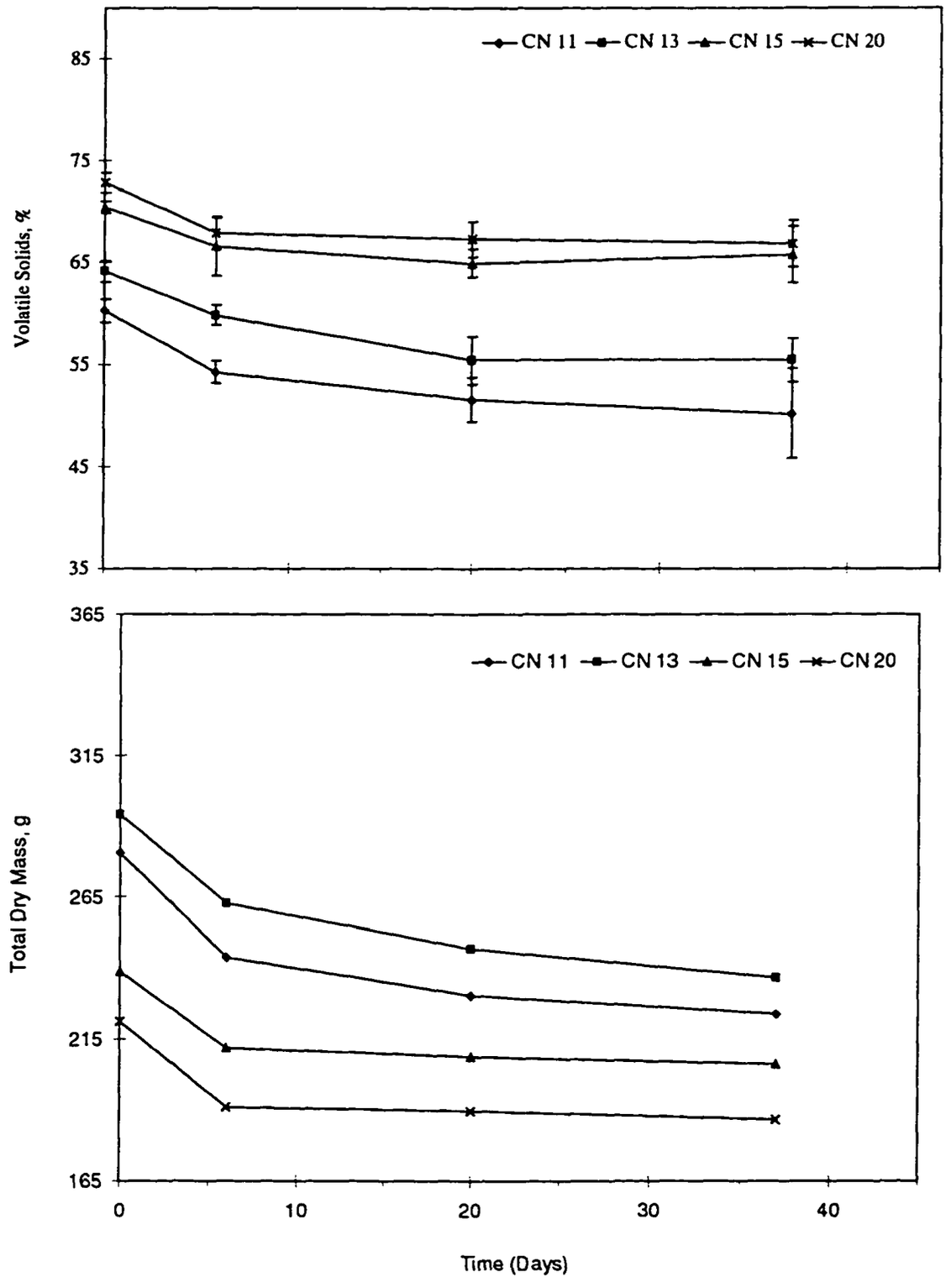



Figure 5.2. Volatile solids concentration (%) and total dry mass (g) versus time (Days) for the four treatments during phase II. Data are means of triplicate samples.

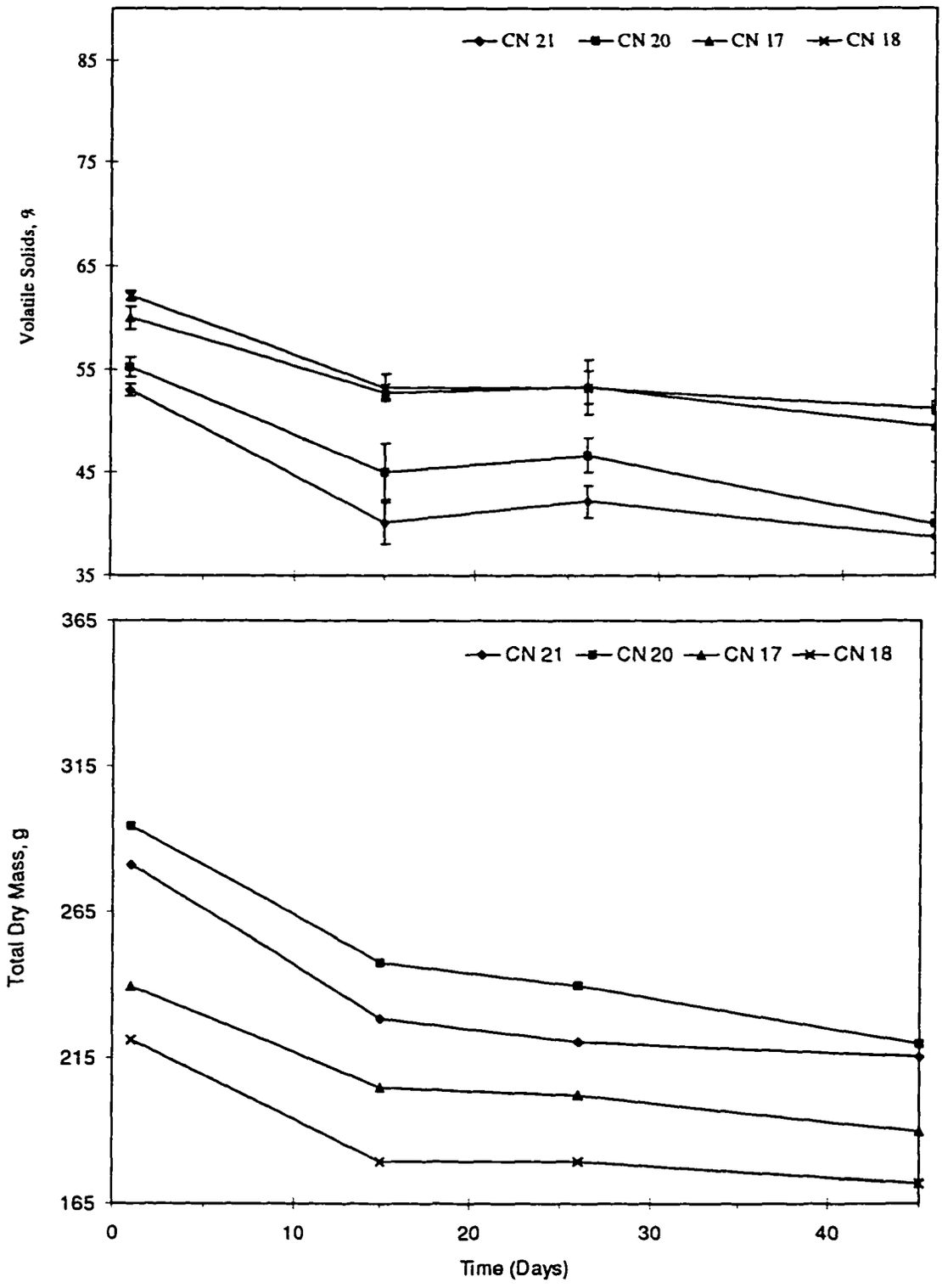



Figure 5.3. Volatile solids concentration (%) and total dry mass (g) versus time (Days) for the four treatments during phase III. Data are means of triplicate samples.

The total dry mass loss and organic matter degradation for each treatment during each phase are shown in Table 5.2. In general, treatments with the lowest percentage of volatile solids had the highest loss of dry mass and organic matter. Although the percentage of crawfish residuals added was about the same at the beginning of phases I, II, and III, for treatment 1 (CN 14, CN 11, and CN 21) and for treatment 2 (CN 17, CN 13, and CN 20), the yield was higher for phase III than phase II or phase I (Table 5.2). Also, for treatments 3 (CN 25, CN 15, and CN 17) and 4 (CN 42, CN 20, and CN 18), the yield was higher during phase III than phase II, although a similar percentage of crawfish residuals was added. This implies that the degradability is not contributed to the crawfish residuals alone, but also to the recycled materials. So the addition of crawfish residuals has provided an extra means for further degradation of the recycled product. In his model, Haug (1993) has considered that recycle product does not contribute any biodegradable fraction of volatile solids by assuming that the entire biodegradable fraction was consumed during the earlier cycle of composting. The results of this study seem to contradict his findings.

## Changes in Total N

Initial N concentration varied in each reactor according to the ratio of crawfish residuals added to the amount of rice hulls or recycled compost. The initial N concentrations, for phase I were 28.7, 23.2, 16.4, and 10.1 mg/g (dry mass basis) for CN 14, CN 17, CN 25, and CN 42 treatments. During phase I, nitrogen concentration in all reactors was continuously decreasing over the 40-day incubation period to final values of 10.5, 10.1, 8.2, and 6.7 mg/g, respectively (Figure 5.4). When the product of phase I was recycled with more crawfish residuals, N concentration became 28.0,

Table 5.2. Final organic matter degradation ($K_{OM}$,%), dry mass loss ($K_{dm}$%), and percent distribution (dry mass basis) of crawfish residuals, rice hulls or recycled compost in feedstock having initial volatile solids, $Vs_i$ (%), for phases I, II, and III. Values are means of triplicate samples.

| Phase I | | | | | |
|---|---|---|---|---|---|
| Treatment | $VS_i$(%) | Rice Hulls (%) | Crawfish Residuals (%) | $K_{OM}$(%) | $K_{dm}$(%) |
| CN 14 | 68.4 | 47 | 53 | 21.3 | 14.6 |
| CN 17 | 72.6 | 57 | 43 | 14.8 | 10.8 |
| CN 25 | 76.2 | 73 | 27 | 13.6 | 10.3 |
| CN 42 | 80.9 | 84 | 16 | 9.6 | 7.8 |
| **Phase II** | | | | | |
| Treatment | $VS_i$(%) | Recycled Compost (%) | Crawfish Residuals (%) | $K_{OM}$(%) | $K_{dm}$(%) |
| CN 11 | 60.3 | 50 | 50 | 33.4 | 20.2 |
| CN 13 | 64.1 | 56 | 45 | 30.4 | 19.5 |
| CN 15 | 70.4 | 57 | 43 | 19.5 | 13.7 |
| CN 20 | 72.9 | 62 | 38 | 21.5 | 15.7 |
| **Phase III** | | | | | |
| Treatment | $VS_i$(%) | Recycled Compost (%) | Crawfish Residuals (%) | $K_{OM}$(%) | $K_{dm}$(%) |
| CN 21 | 52.9 | 53 | 47 | 43.8 | 23.2 |
| CN 20 | 55.2 | 59 | 41 | 46.0 | 25.4 |
| CN 17 | 59.9 | 60 | 40 | 34.5 | 20.7 |
| CN 18 | 62.1 | 63 | 37 | 35.9 | 22.3 |

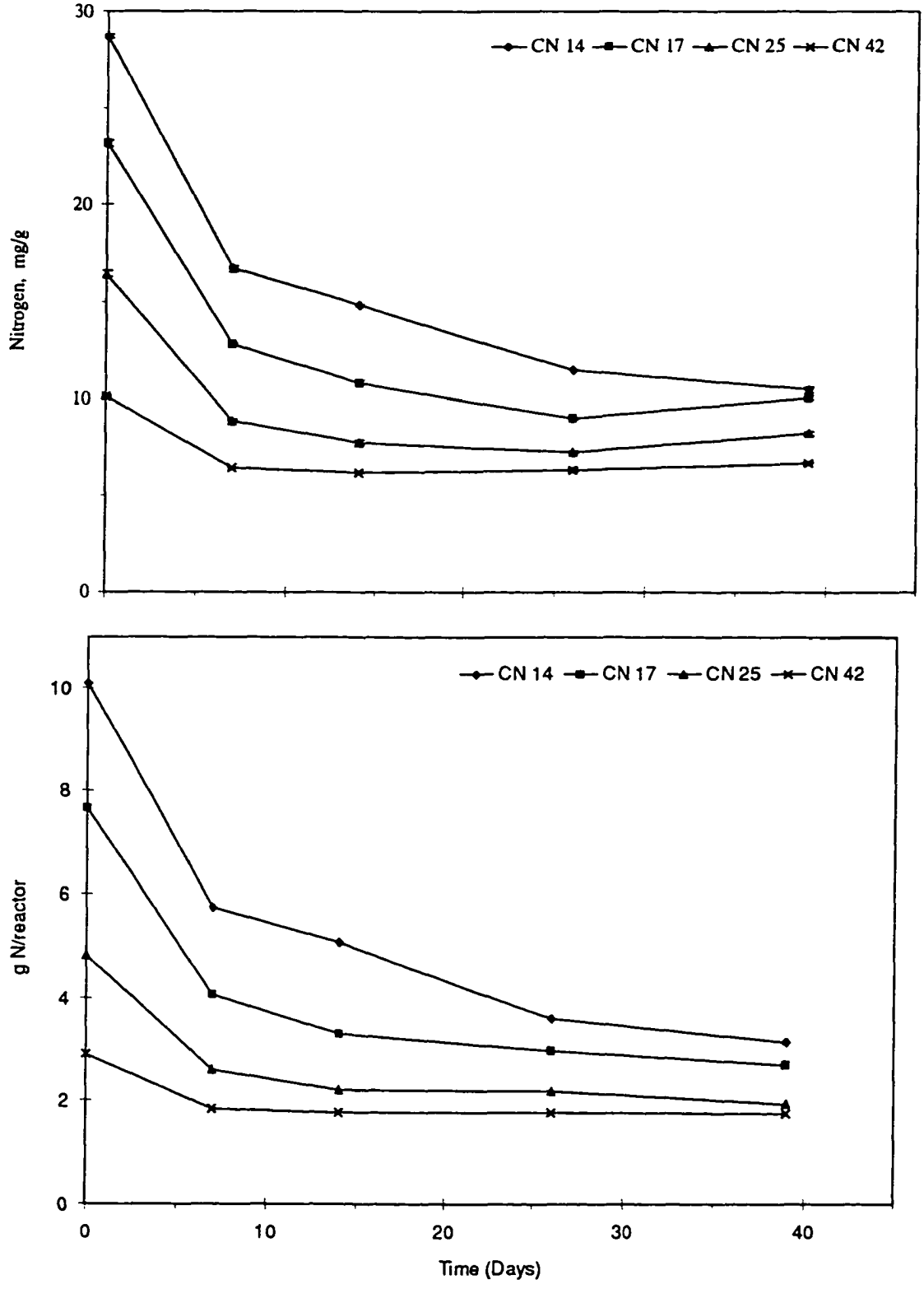



Figure 5.4. Mean total N concentration (mg/g) and content (g N) per reactor versus time for the four treatments during phase I.

26.9, 23.7, and 19.5 mg/g corresponding to new C:N ratios of 11, 13, 15, and 20, respectively. Also, in phase II, N concentration for all treatments dropped simultaneously to final values of 12.0, 11.5, 10.1, and 8.5 g/kg for CN 11, CN 13, CN 15, and CN 20 treatments, respectively (Figure 5.5). The treatments in phase III having initial N concentrations of 13.5, 14.0, 15.0, and 14.2 mg/g corresponded to initial C:N ratios of 21, 20, 17, and 18, respectively. No significant variation in N concentration (dry mass basis) was observed for all treatments in phase III (Figure 5.6). This is probably due to the balanced loss of N with that of the total organic matter.

Nitrogen content in each reactor was continuously decreasing through out the composting period (figures 5.4, 5.5, and 5.6 and tables 5.3, 5.4, and 5.5). Treatments with the highest N content observed the highest drop. This drop occured during the first 10 days due to high $NH_3$ volatilization. After the second week, N content tended to level off between 2 and 4 gN/reactor or a N concentration between 6 and 14 mg/g. N losses during the phase III were minimum. Recycling a recalcitrant compost product such as rice hulls with a nitrogenous source such as crawfish residuals may lead to a conservation of N toward the latest recycling phase.

## Characterization of Final Product

Nutrient analysis of compost samples at the end of the experiment showed that the treatments receiving the highest amount of crawfish residuals have the highest final nutrient concentration (Table 5.6). The concentration of Si did not vary significantly among treatments. The repetitive addition of crawfish residuals increases the concentration of important nutrients like P, K, Mg, Mn, S, and Ca. These high

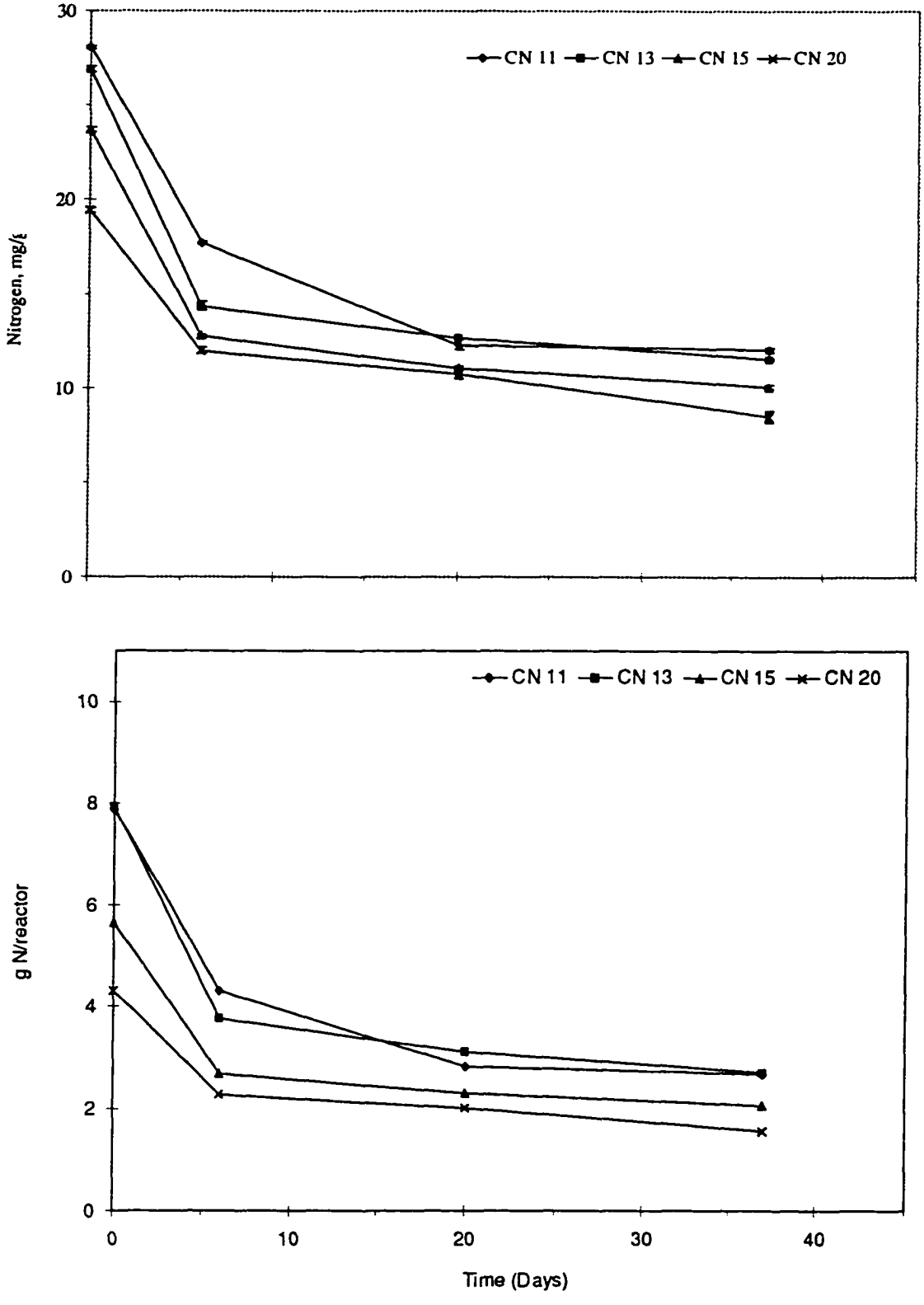



Figure 5.5. Mean total N concentration (mg/g) and content (g N) per reactor versus time for the four treatments during phase II.

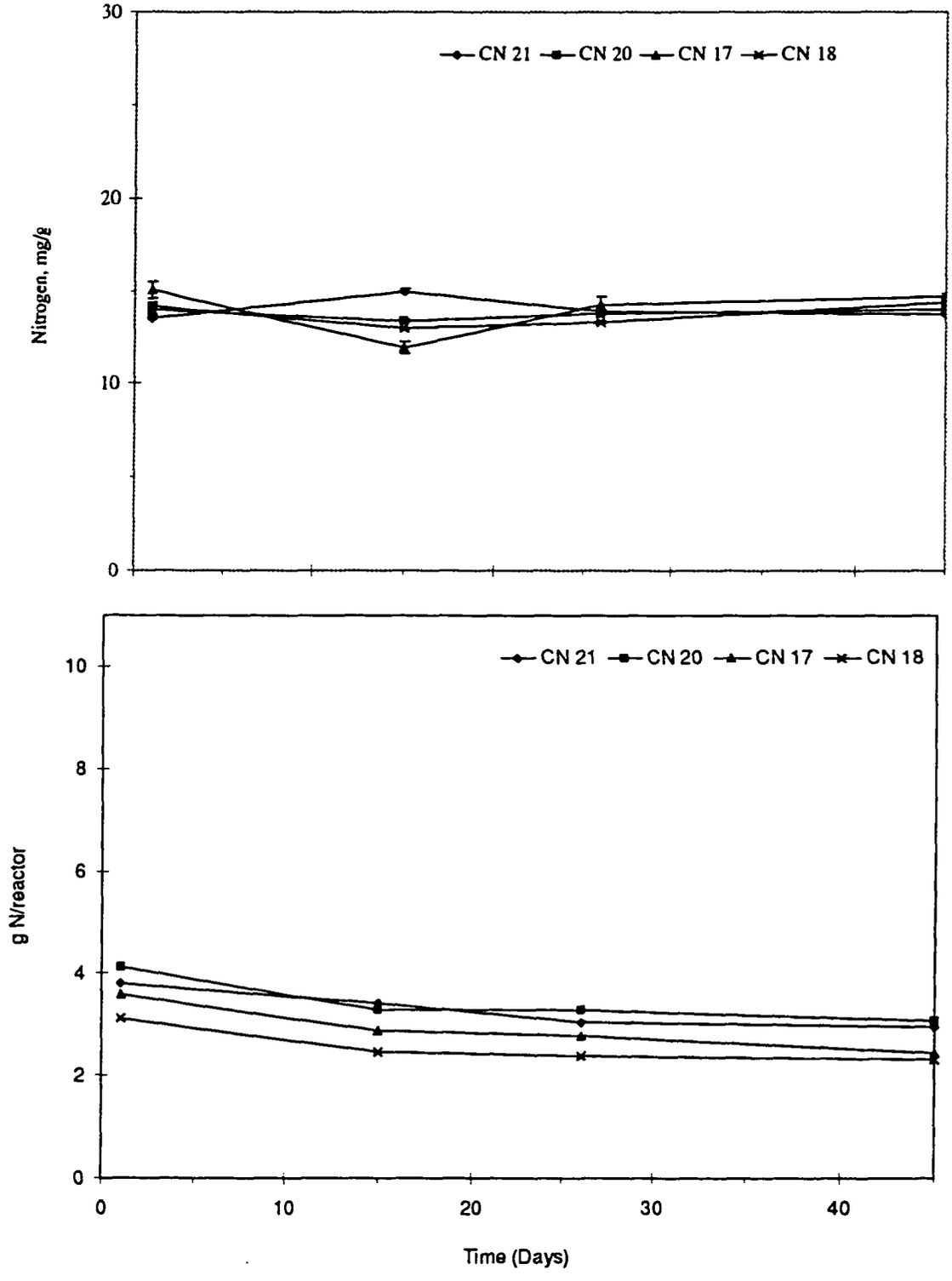



Figure 5.6. Mean total N concentration (mg/g) and content (g N) per reactor versus time for the four treatments during phase III.

Table 5.3. Average N loss from each treatment, for phase I, expressed as the cumulative mass loss and percentage loss from initial amount.

| Time | CN 14 | | CN 17 | | CN 25 | | CN 42 | |
|---|---|---|---|---|---|---|---|---|
| (Days) | g N Lost per Reactor | % N Lost of Initial Amount | g N Lost per Reactor | % N Lost Initial Amount | g N Lost per Reactor | % N Lost Initial Amount | g N Lost per Reactor | % N Lost Initial Amount |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 4.35 | 43.1 | 3.60 | 47.0 | 2.22 | 46.0 | 1.56 | 36.7 |
| 14 | 5.00 | 49.6 | 4.35 | 56.8 | 2.62 | 54.2 | 1.14 | 39.1 |
| 26 | 6.49 | 64.3 | 4.68 | 61.2 | 2.66 | 55.1 | 1.15 | 39.5 |
| 39 | 6.96 | 68.9 | 4.95 | 64.7 | 2.91 | 60.2 | 1.18 | 40.5 |

Table 5.4. Average N loss from each treatment, for phase II, expressed as the cumulative mass loss and percentage loss from initial amount.

| Time | CN 11 | | CN 13 | | CN 15 | | CN 20 | |
|---|---|---|---|---|---|---|---|---|
| (Days) | g N Lost per Reactor | % N Lost of Initial Amount | g N Lost per Reactor | % N Lost Initial Amount | g N Lost per Reactor | % N Lost Initial Amount | g N Lost per Reactor | % N Lost Initial Amount |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 3.55 | 45.1 | 4.14 | 52.3 | 2.96 | 52.2 | 2.01 | 46.7 |
| 20 | 5.03 | 63.9 | 4.79 | 60.5 | 3.35 | 59.2 | 2.27 | 52.7 |
| 37 | 5.18 | 65.7 | 5.19 | 65.5 | 3.59 | 63.4 | 2.73 | 63.3 |

Table 5.5. Average N loss from each treatment, for phase III, expressed as the cumulative mass loss and percentage loss from initial amount.

| Time | CN 21 | | CN 20 | | CN 17 | | CN 18 | |
|---|---|---|---|---|---|---|---|---|
| (Days) | g N Lost per Reactor | % N Lost of Initial Amount | g N Lost per Reactor | % N Lost Initial Amount | g N Lost per Reactor | % N Lost Initial Amount | g N Lost per Reactor | % N Lost Initial Amount |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0.38 | 9.9 | 0.82 | 19.8 | 0.71 | 19.8 | 0.66 | 21.2 |
| 26 | 0.74 | 19.4 | 0.82 | 19.8 | 0.80 | 22.3 | 0.74 | 23.7 |
| 45 | 0.85 | 22.4 | 1.05 | 25.4 | 1.14 | 31.8 | 0.80 | 25.7 |

Table 5.6. Selected properties of final compost product for all treatments (mg/g).

| Treatment | K | P | Na | Mg | Mn | Ca | S | Si |
|---|---|---|---|---|---|---|---|---|
| CN 21 | 6.3 | 10.2 | 5.5 | 2.4 | 0.34 | 150.6 | 3.6 | 0.068 |
| CN 20 | 5.9 | 9.4 | 5.0 | 2.3 | 0.33 | 138.9 | 3.4 | 0.075 |
| CN 17 | 5.6 | 8.0 | 4.5 | 2.0 | 0.32 | 118.4 | 3.0 | 0.064 |
| CN 18 | 5.3 | 7.5 | 4.1 | 1.9 | 0.30 | 111.0 | 2.9 | 0.065 |
| $LSD_{0.05}$* | 0.3 | 0.4 | 0.2 | 0.1 | 0.01 | 6.1 | 0.1 | 0.02 |

* Least significance difference

concentrations provide plant nutrients and improve soil quality. Although high concentration of Na may cause damage to crop, the concentration of Na in crawfish compost remains lower than poultry litter compost (Lu et al., 1997). It was noted earlier that multiple addition of crawfish residuals reduces the VS concentration (i.e. increases ash concentration). Since Ca is a major constituent of ash, the increase of ash concentration lead to an increase in Ca concentration as well. This is why Ca concentration ranged between 110-150 mg/g.

## Specific Oxygen Uptake Rate

Specific oxygen uptake rate (SOUR) curves were obtained by direct measurements of compost samples at different time intervals throughout the process. A general trend was observed for all treatments in all phases of the experiment (figures 5.7, 5.8, and 5.9). Oxygen consumption was at its peak during the first or second day for all treatments of all phases of the experiment. A sharp decline during phase I and phase II and a gradual decline during phase III was then followed, which implies a slowing down in microbial activity. After the second week, SOUR values were below 1.5 (mg $O_2$/g VS)/hr for all phases. During phase I, for most part of the experiment, treatment 1 (CN 14) observed the highest oxygen consumption. This implies that more substrate was readily available from the mixture of treatment 1 (CN 14) than to from the others. During phase II and phase III, there was no significant difference in SOUR among treatments except for the first day. Therefore, higher microbial activity was relatively high during the early stage of composting and tends to correspond to the amount of crawfish residuals added.

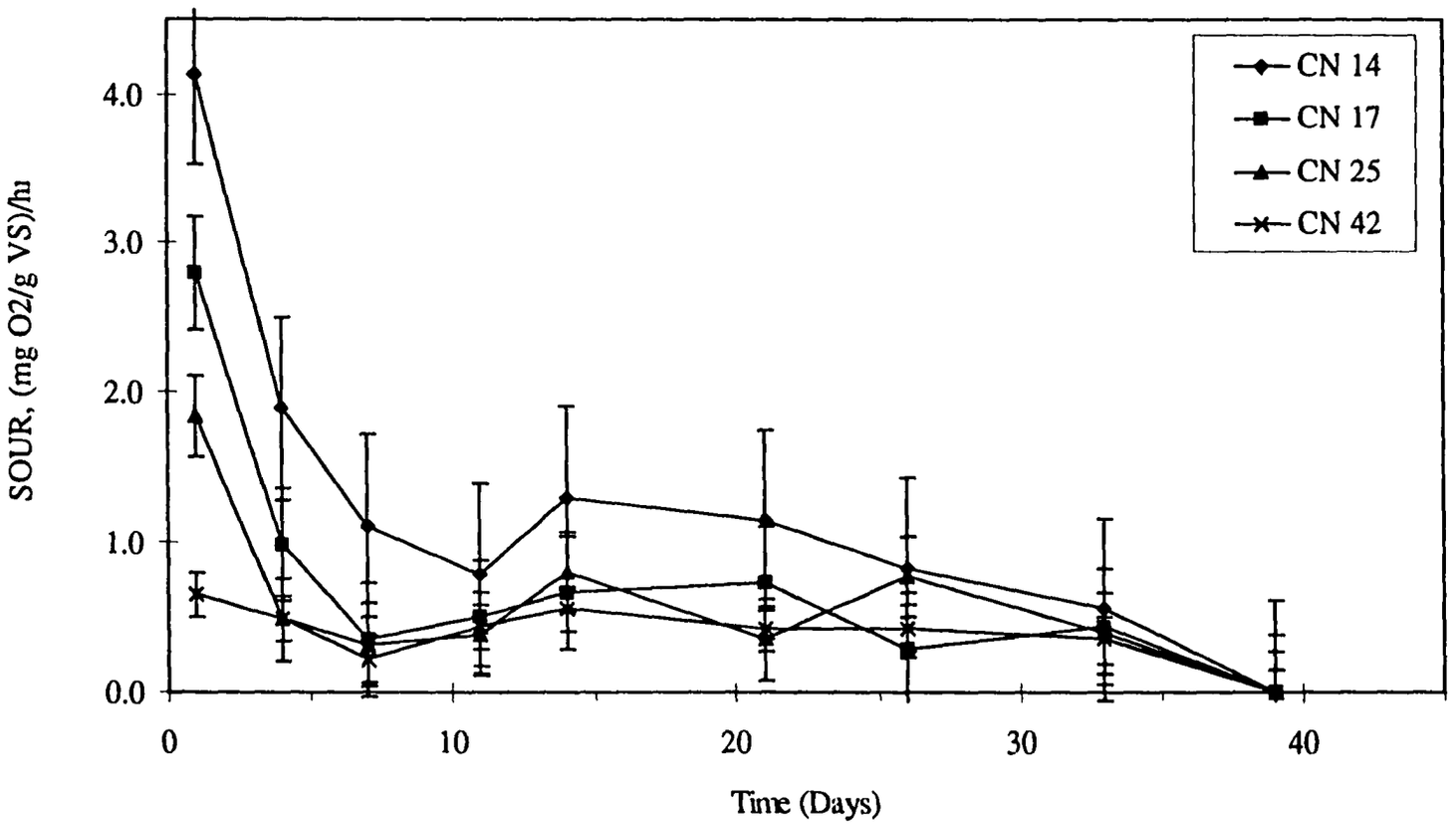



Figure 5.7. Mean compost specific oxygen uptake rate (SOUR) versus time for the four treatments during phase I.

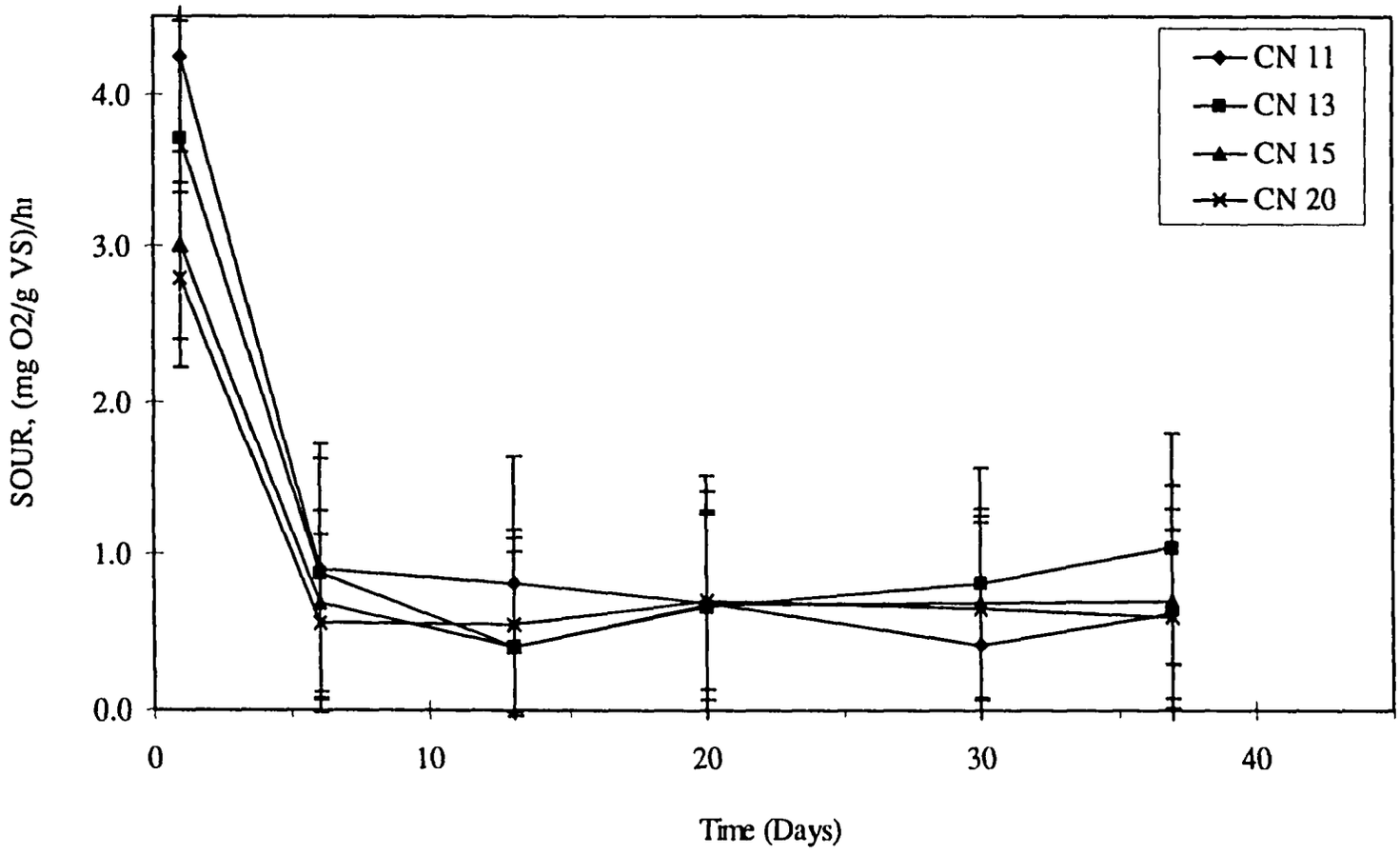



Figure 5.8. Mean compost specific oxygen uptake rate (SOUR) versus time for the four treatments during phase II.

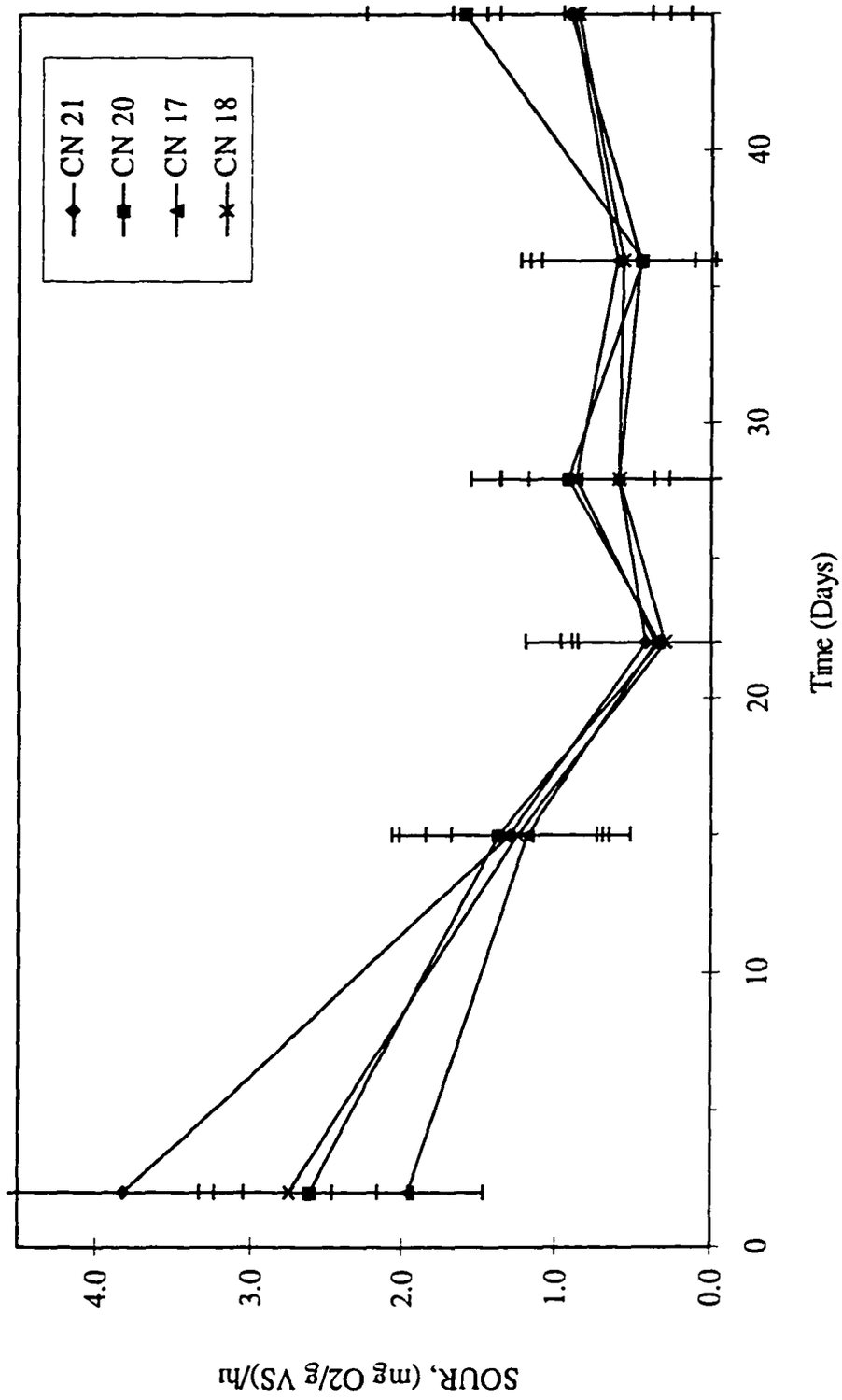



Figure 5.9. Mean compost specific oxygen uptake rate (SOUR) versus time for the four treatments during phase III.

### $CO_2$ Production Rate

At the beginning of the compost process, fresh mixture generates ponderous $CO_2$ emission due to high microbial respiration. As compost ages and available substrate is reduced, $CO_2$ production decreases. During phase I, initial $CO_2$ production rates were between 5 and 11 (mg $CO_2$-C/g C)/day (Figure 5.10). After the first two weeks, CN 25 and CN 42 treatments had a sharp drop. The other two treatments (CN 14 and CN 17) maintained relatively high production rates through the end of phase I. The continuos high $CO_2$ production for CN 14 corresponded to high substrate availability. Phases II and III $CO_2$ production rates were very similar among different treatments (figures 5.11 and 5.12). Unlike phase II and III, a variation in $CO_2$ production among treatments was observed in phase I. This phenomenon is probably due to the acclimation of the microbial community resulting from the mixing of raw heterogeneous organic materials (rice hulls and crawfish residuals). For phase II and III, a high variation of $CO_2$ production was observed among samples of the same treatment during the early period than the final period of composting. $CO_2$ production variation was comparable for all treatments, due to the establishment of similar microbial populations. Final $CO_2$ evolution rates were less than 4 (mg $CO_2$-C/g C)/day for all phases, implying a stable compost for all treatments.

## 5.4 Conclusions

Biodegradability analysis conducted in this experiment showed that rice hulls and crawfish residuals can be composted when initial C:N ratio is within 11-42; however, mixtures containing a higher percentage of crawfish residuals to rice hulls or

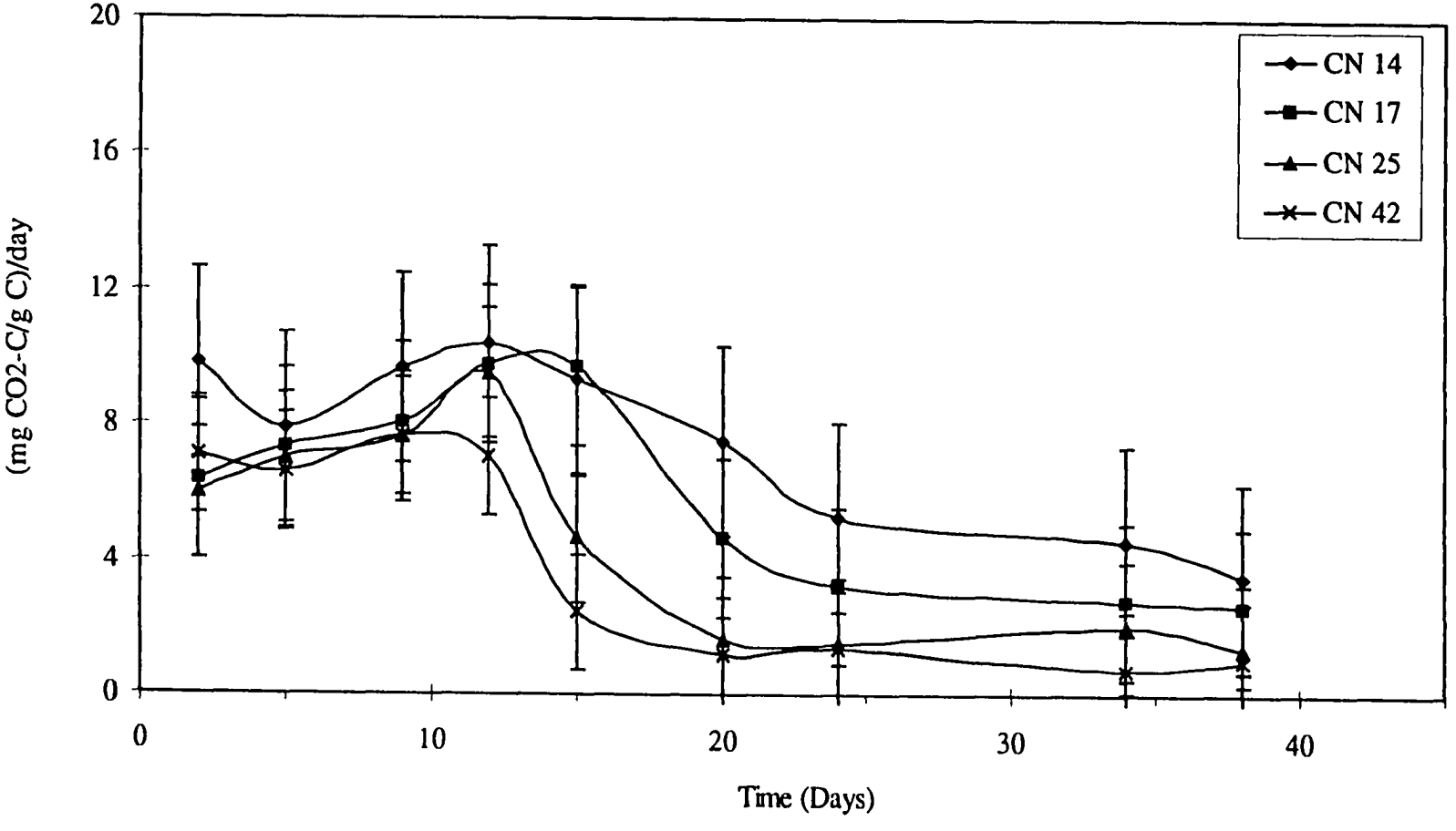



Figure 5.10. Mean compost $CO_2$ production rate versus time for the four treatments during phase I.

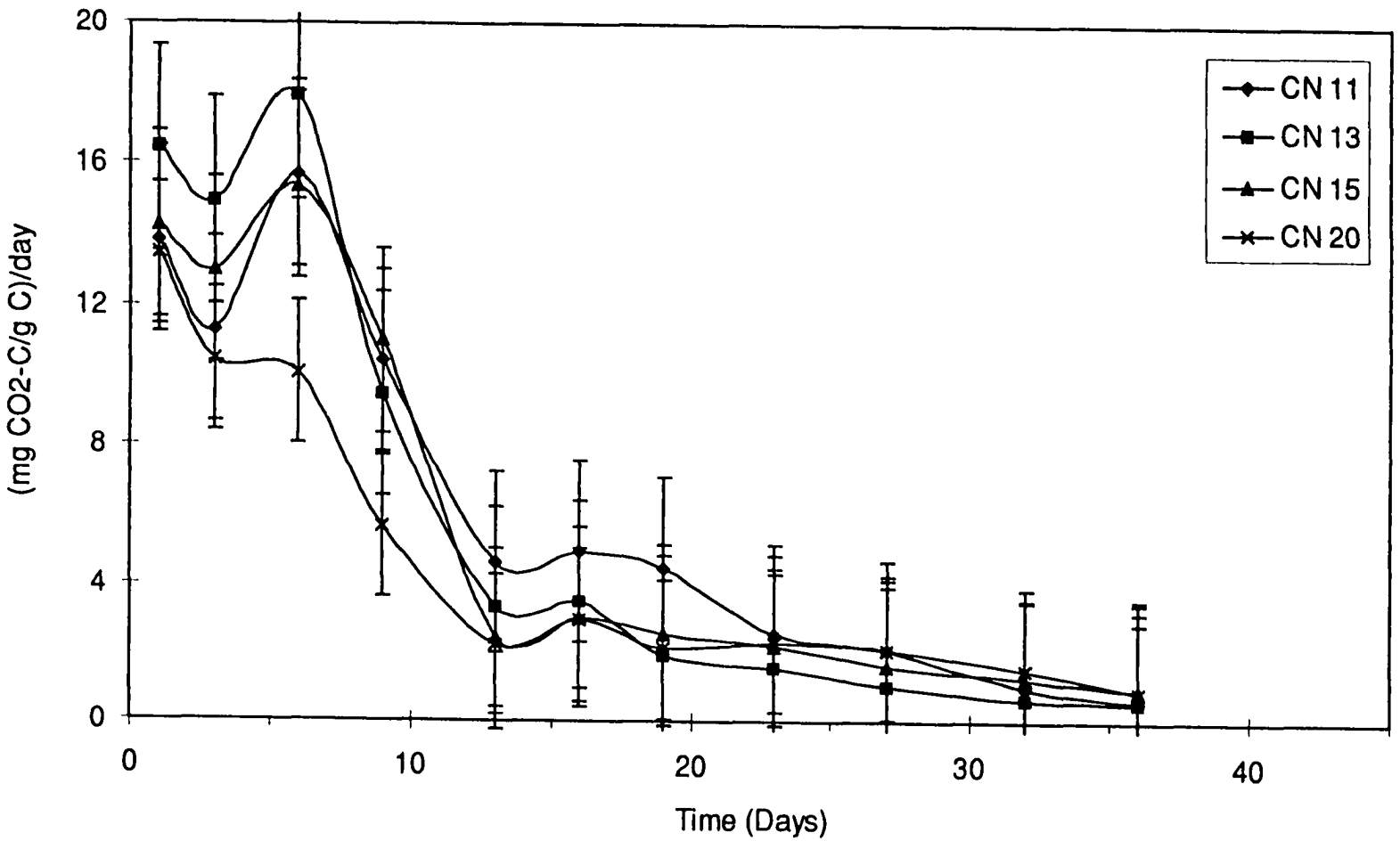



Figure 5.11. Mean compost $CO_2$ production rate versus time for the four treatments during phase II.

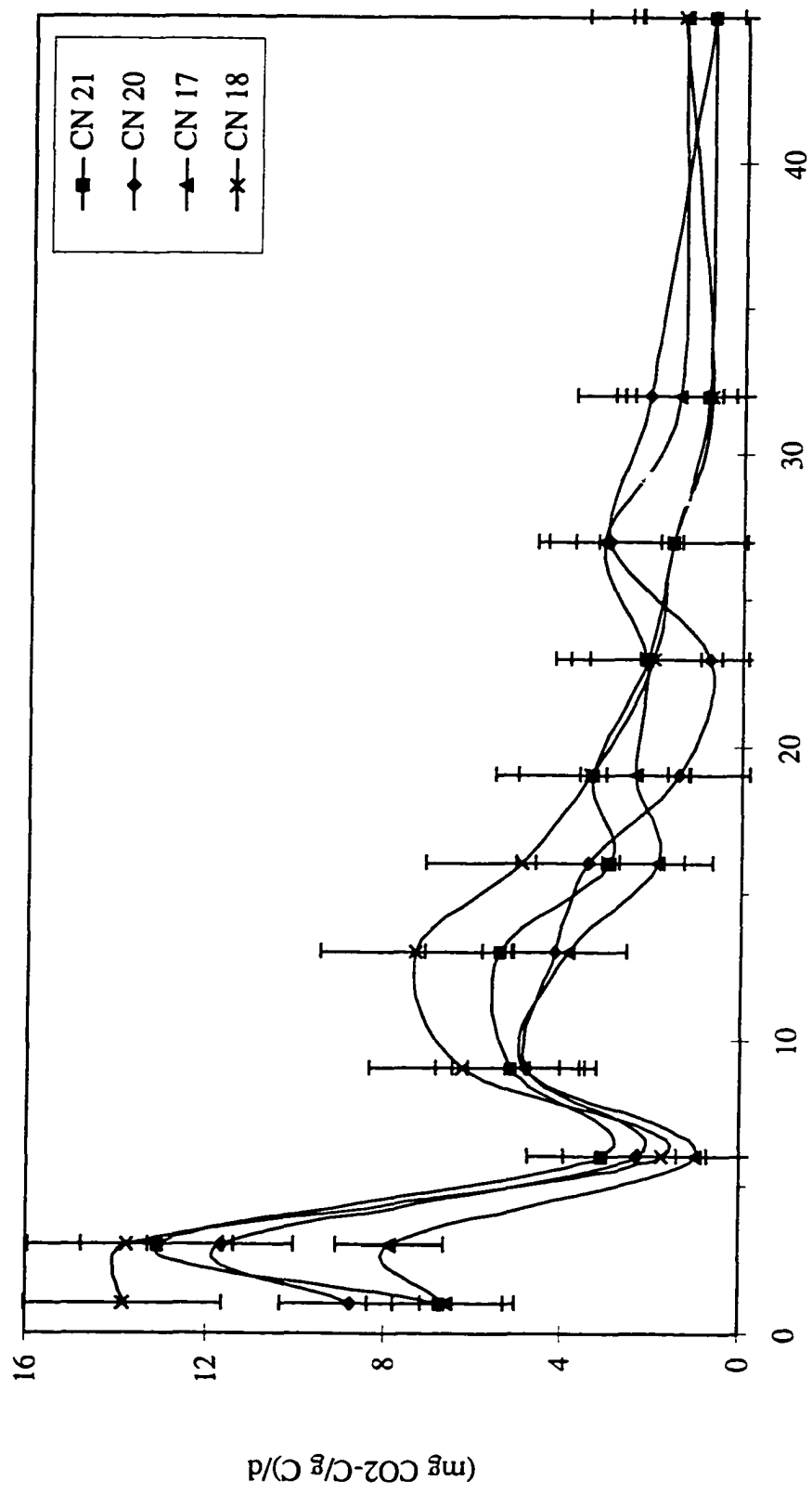



Figure 5.12. Mean compost $CO_2$ production rate versus time for the four treatments during phase III.

recycled product, tend to degrade at a faster rate. The results also showed that the initial C:N ratio is not a good indicator of the subsequent composting of lignocellulotic feedstock. In addition to N availability, the extent of C degradability must also be taken into account. The addition of a nitrogenous feedstock, such as crawfish residuals, to recycled compost had a positive effect in improving the degradability of the recycled compost and increasing the N concentration of the final compost product. Rice hulls, having good structural property (i.e. high porosity, low bulking density), proved to be an excellent bulking agent for composting crawfish residuals which provide readily available substrate for microorganims. Further research is needed to quantify the degradation of lignocellulotic materials during repetitive composting with nitrogenous feedstock.

Commonly used biodegradability test such as the volatile solids concentration does not discriminate among readily, less readily, and not metabolized materials during composting. However, this test could be used as an overall indicator of biodegradability. Tests such as SOUR and $CO_2$ production rate are preferable for direct measurement of compost activity as well as an indication of the extent of the composting process.

## 5.5 References

American Public Health Association (APHA), American Water Works Association, and Water Pollution Control Federation. 1992. Standard methods for the examination of water and wastewater. 18th edition. APHA, Washington, D.C.

Crawford, S. L. 1976. Microbial degradation of lignocelluloses: The lignin component. Applied Environmental Microbiology, 31:714-717.

Feldman, K. 1995. Stability index determination. Biocycle, 36(11)68-69.

Garcia, C., T. Hernandez, and F. Costa. 1991. Changes in carbon fractions during composting and maturation of organic wastes. Environmental Management, 15(3):433-439.

Haug, R. T. 1993. The practical handbook of compost engineering. Lewis Publishers, Boca Raton, Florida.

Iannotti, D. A., T. Pang, B. L. Toth, D. L. Elwell, H. M. Keener, and H. A. J. Hoitink. 1993. A quantitative respirometric method for monitoring compost stability. Compost Science and Utilization, 1(3):52-65.

Lu, N., J. H. Edwards, and R. H. Walker. 1997. Ionic activity in soil solution as affected by application of newsprint and nitrogen sources. Compost Science and Utilization, 5(2):68-83.

Mizuki, E., S. Okumura, H. Saito, and S. Murao. 1993. Formation of silicon carbide from rice husks using enzymatic methods for carbon control. Bioresource Technology, 44:47-51.

Regan, R. W. and J. S. Jeris. 1970. A review of the decomposition of cellulose and refuse. Compost Science, v. 11, January/February, 17-20.

Rynk, R. 1992. On-farm composting handbook. NRAES-54, Northeast Regional Agricultural Engineering Service, Ithaca, NY.

Shuler, M. L. 1980. Utilization and recycle of agricultural wastes and residues. CRC Press, Boca Raton, Florida.

# CHAPTER 6

## SUMMARY AND FURTHER RESEARCH

Many agricultural and food processing by-products constitutes a waste management challenge for the state of Louisiana as well as in many other part of the world. Integrating the management of different by-products by co-composting requires a scientific approach in understanding the processes and transformations involved.

Characterizing the composting process helps evaluate the benefit of different feedstock and mixture ratios. All bulking agents (bagasse, bark, rice hulls, and wood chips) used in this study performed well in co-composting crawfish residuals. Mixtures with bagasse had the greatest loss of volatile solids and had relatively the highest N concentration. Rice hull mixtures maintained good structure and lost a notable percentage of their original volatile solids after the 50-day composting period.

Some composting operations may pose an environmental threat resulting from leachate and runoff emanating from the composting site. Design of proper system to alleviate the potential problem would necessitate an understanding of the factors involved. Assessing the leachate and runoff can provide valuable information for better design of compost facilities. During composting crawfish residuals and rice hulls excessive amounts of organics and inorganics were leached and ran off throughout the composting period. Organic C and ammonia were released mostly in the early stages of composting. Release of nitrate and other nutrients resulted from mineralization of organic compounds. Recycling of leachate and runoff into active compost proved to be efficient during the early stage of decomposition. Recycled

leachate and runoff would replenish moisture and elements losses during composting. Further research is needed to characterize leachate and runoff and nutrient retention of different feedstock.

The major piece of information needed to practically evaluate the operation of the composting process is the biodegradability of the materials used. To optimize the composting process, it is essential to minimize materials handling and increase product quality. This could be accomplished by reusing the compost product with putrescent or nitrogenous feedstock.

Crawfish residuals were successfully degraded when composted with rice hulls at different mixing ratios. Mixtures having the highest crawfish residuals to rice hulls or to recycled compost had the highest degradability and microbial activity. The suitability of recycling compost product with additional crawfish residuals was confirmed. Reuse of recycled compost product induced higher degradation in the recycled product as well as fully degraded the crawfish residuals.

Additional work is needed to investigate the biodegradability of different materials during aerobic decomposition. Various operating conditions and different feedstock mixtures could be evaluated to optimize the biodegradability rate. Simple procedures and refined methods need to be developed to determine biodegradability for both design and operation of compost facility.

# APPENDIX A

# ANALYSIS OF VARIANCE (ANOVA) TABLES

Table A.1. Summary and ANOVA: Percent reduction of volatile solids over the first two weeks of composting crawfish residuals with wood chips, rice hulls, bagasse, and bark.

Summary

| Mixture | Count | Mean | Variance |
|---|---|---|---|
| Wood Chips | 3 | 0.439852 | 8.689801 |
| Rice Hulls | 3 | 17.36035 | 1.422231 |
| Bagasse | 3 | 2.477873 | 43.69262 |
| Bark | 3 | 13.96653 | 10.43681 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | Fcrit |
|---|---|---|---|---|---|---|
| Between Mixtures | 628.817 | 3 | 209.6057 | 13.05112 | 0.001895 | 4.06618 |
| Within Mixtures | 128.4829 | 8 | 16.06036 | | | |
| Total | 757.2999 | 11 | | | | |

Table A.2. Summary and ANOVA: Total percent reduction of volatile solids over 50 days of composting crawfish residuals with wood chips, rice hulls, bagasse, and bark.

Summary

| Mixture | Count | Mean | Variance |
|---|---|---|---|
| Wood Chips | 3 | 12.07285 | 0.040077 |
| Rice Hulls | 3 | 22.65258 | 0.092836 |
| Bagasse | 3 | 27.58742 | 5.947991 |
| Bark | 3 | 21.33096 | 0.063729 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | Fcrit |
|---|---|---|---|---|---|---|
| Between Mixtures | 377.6906 | 3 | 125.8969 | 81.95566 | 2.40E-06 | 4.06618 |
| Within Mixtures | 12.28927 | 8 | 1.536158 | | | |
| Total | 389.9799 | 11 | | | | |

Table A.3. Summary and ANOVA: Percent reduction of organic C (ash basis) over 50 days of composting crawfish residuals with wood chips, rice hulls, bagasse, and bark.

Summary

| Mixture | Count | Mean | Variance |
|---|---|---|---|
| Wood Chips | 3 | 39.9846 | 0.183579 |
| Rice Hulls | 3 | 43.68648 | 0.214223 |
| Bagasse | 3 | 55.30851 | 1.725777 |
| Bark | 3 | 49.43589 | 2.387102 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | Fcrit |
|---|---|---|---|---|---|---|
| Between Mixtures | 405.351 | 3 | 135.117 | 119.8196 | 5.48E-07 | 4.06618 |
| Within Mixtures | 9.021363 | 8 | 1.12767 | | | |
| Total | 414.3724 | 11 | | | | |

Table A.4. Summary and ANOVA: Percent reduction of total N (ash basis) over 50 days of composting crawfish residuals with wood chips, rice hulls, bagasse, and bark.

Summary

| Mixture | Count | Mean | Variance |
|---|---|---|---|
| Wood Chips | 3 | 47.70704 | 608.6845 |
| Rice Hulls | 3 | 52.40102 | 32.45356 |
| Bagasse | 3 | 17.97153 | 271.7914 |
| Bark | 3 | 35.01298 | 788.0984 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | Fcrit |
|---|---|---|---|---|---|---|
| Between Mixtures | 2134.138 | 3 | 711.3795 | 1.672823 | 2.49E-01 | 4.06618 |
| Within Mixtures | 3402.056 | 8 | 425.257 | | | |
| Total | 5536.194 | 11 | | | | |

Table A.5. Summary and ANOVA: Volatile solids content at the beginning of phase III for the four treatments.

Summary

| Treatment | Count | Mean | Variance |
|---|---|---|---|
| CN 21 | 3 | 52.9485 | 0.25031 |
| CN 20 | 3 | 55.2084 | 1.14559 |
| CN 17 | 3 | 59.9488 | 0.93044 |
| CN 18 | 3 | 62.0882 | 0.32733 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | Fcrit |
|---|---|---|---|---|---|---|
| Between Treatments | 159.017 | 3 | 53.0057 | 79.8981 | 2.6E-06 | 4.06618 |
| Within Treatments | 5.30732 | 8 | 0.66342 | | | |
| Total | 164.324 | 11 | | | | |

# APPENDIX B

## VARIATIONS OF TEMPERATURE, PERCENT OXYGEN, AND MOISTURE CONTENT FOR ALL 12 REACTORS DURING PHASES I, II, AND III

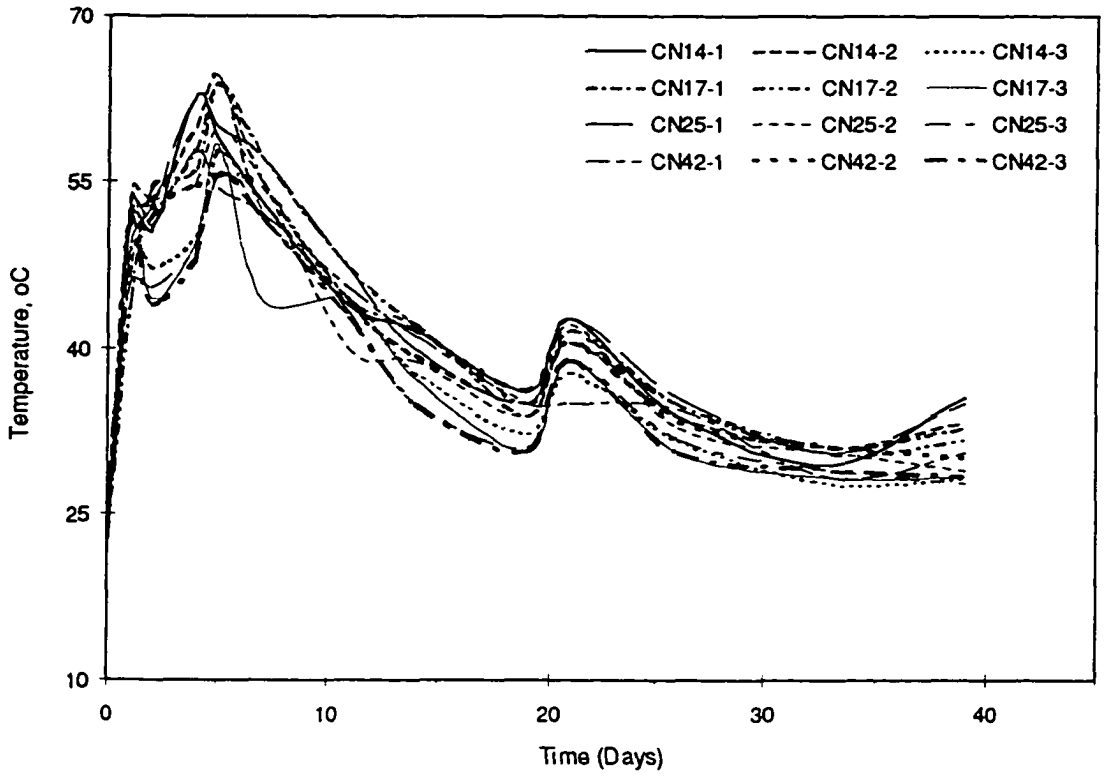



Figure B.1. Variation of all 12 compost reactors temperature during phase I.

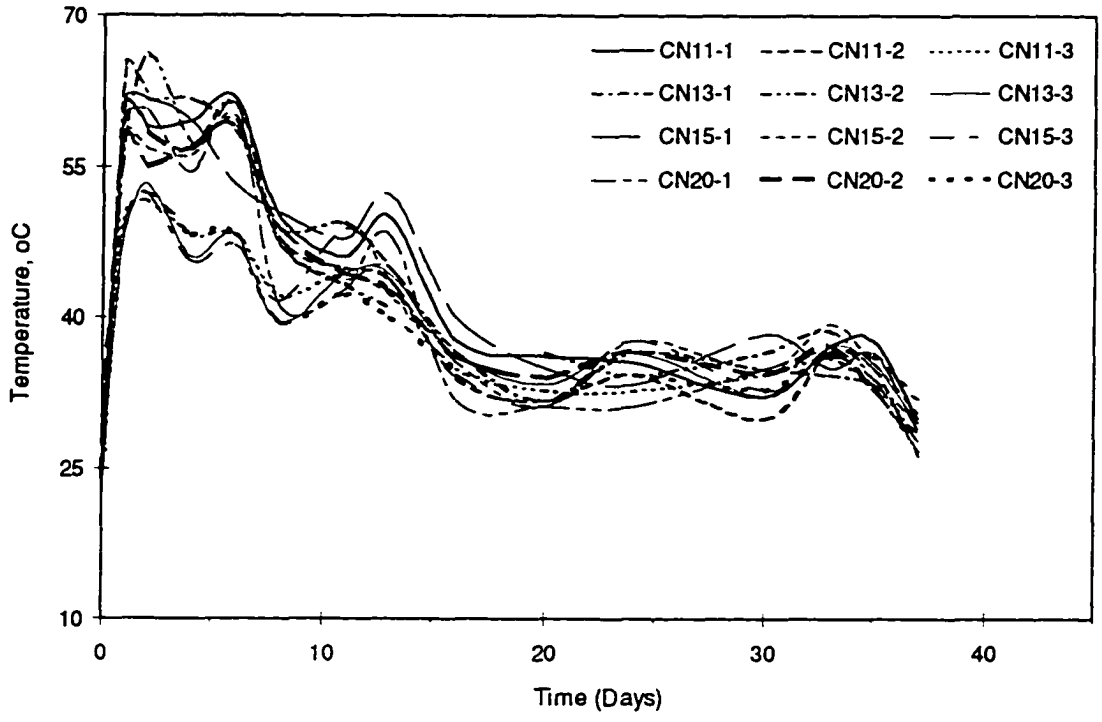



Figure B.2. Variation of all 12 compost reactors temperature during phase II.

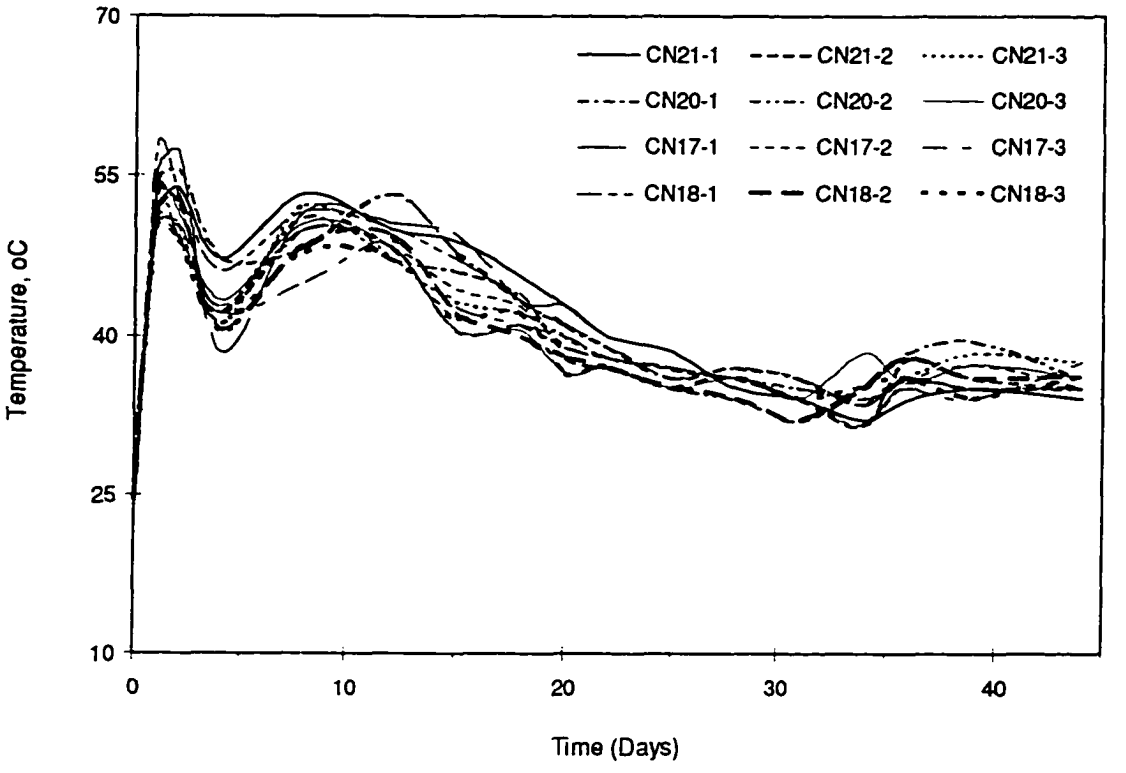



Figure B.3. Variation of all 12 compost reactors temperature during phase III.

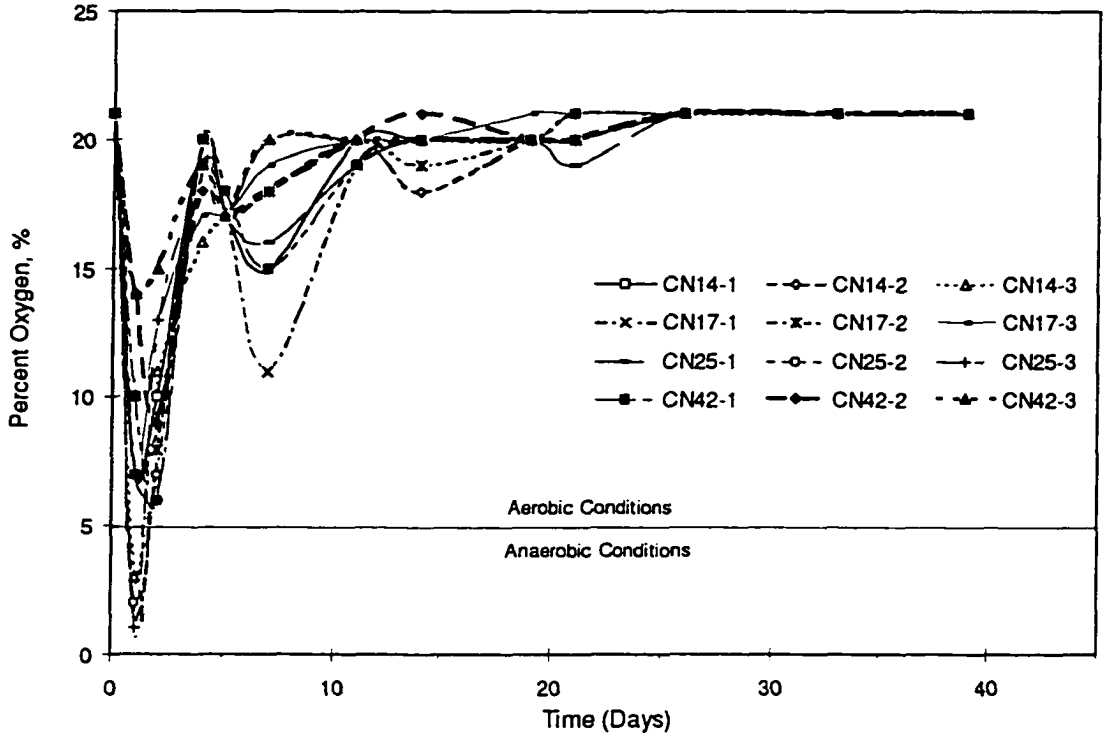



Figure B.4. Variation of compost percent oxygen with time in all 12 reactors during phase I.

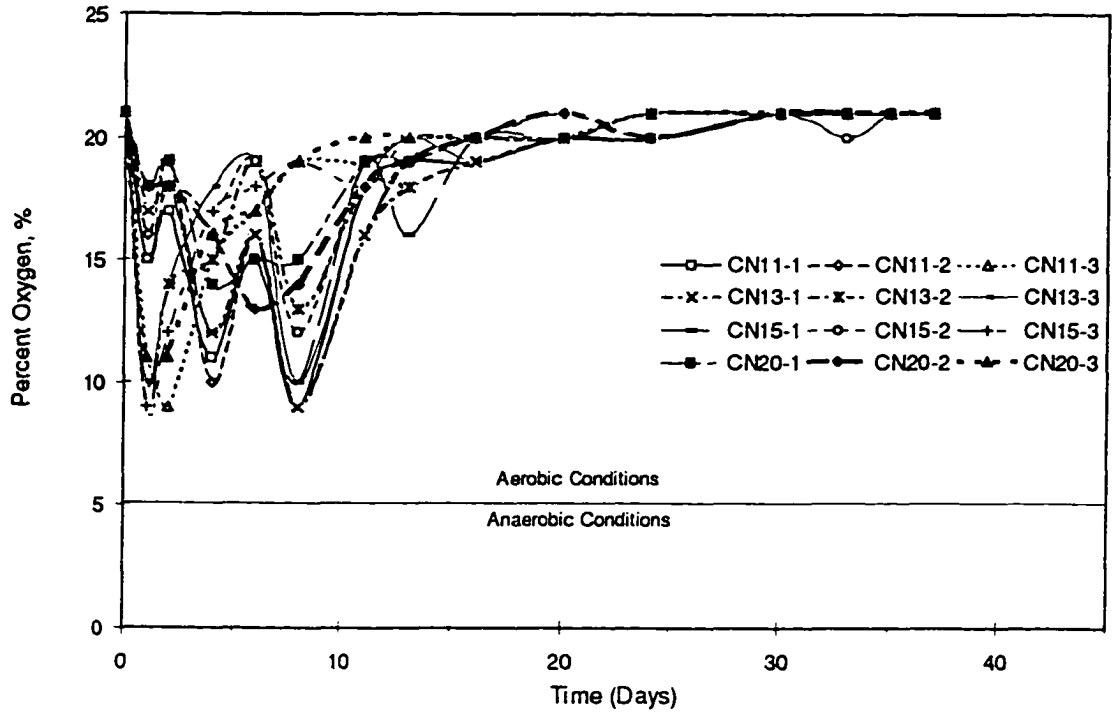



Figure B.5. Variation of compost percent oxygen with time in all 12 reactors during phase II.

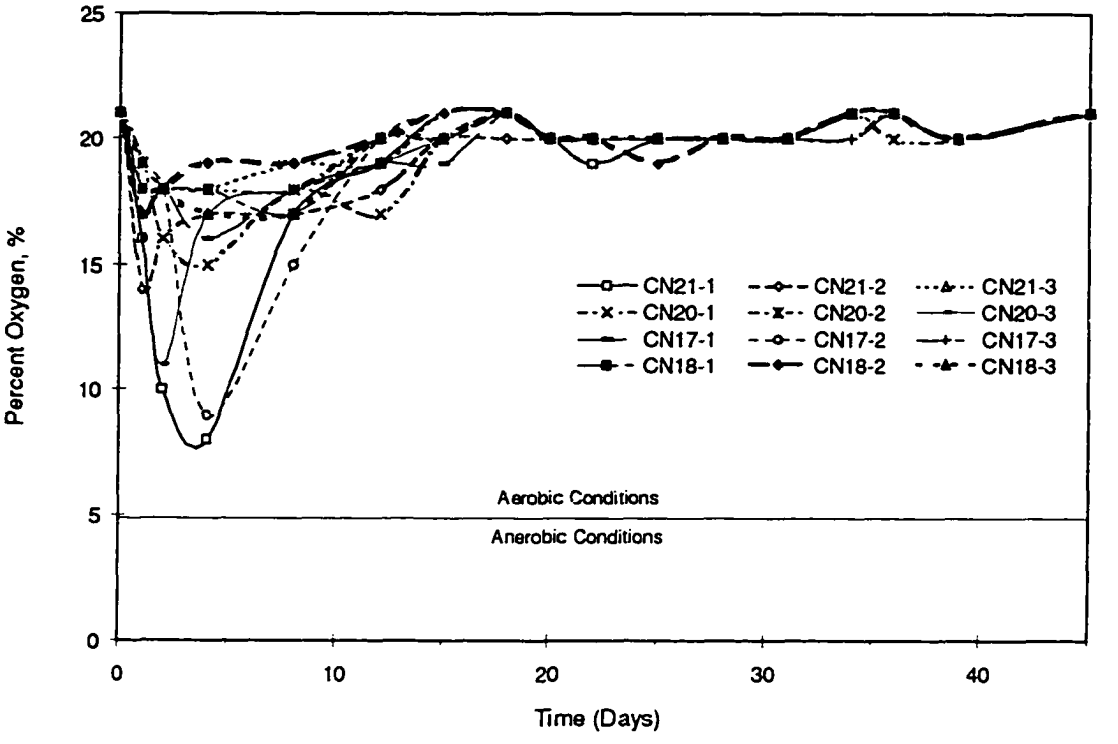



Figure B.6. Variation of compost percent oxygen with time in all 12 reactors during phase III.

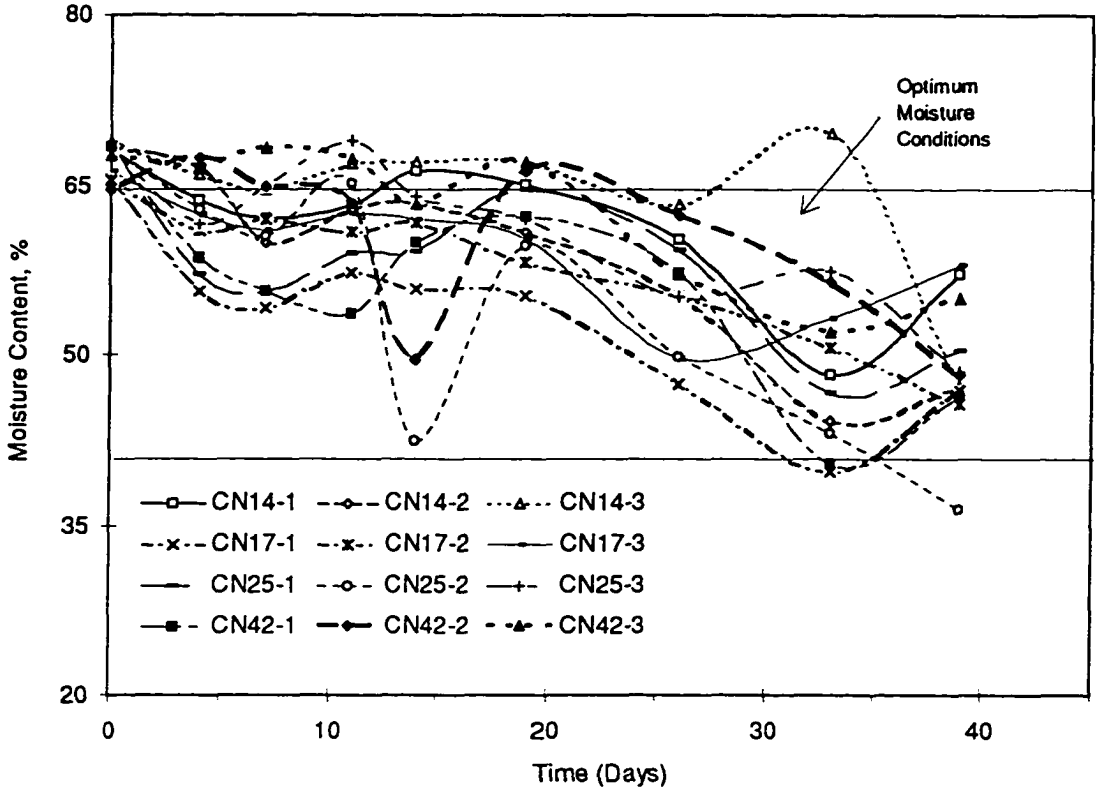



Figure B.7. Variation of compost moisture content (wet mass basis) with time in all 12 reactors during phase I.

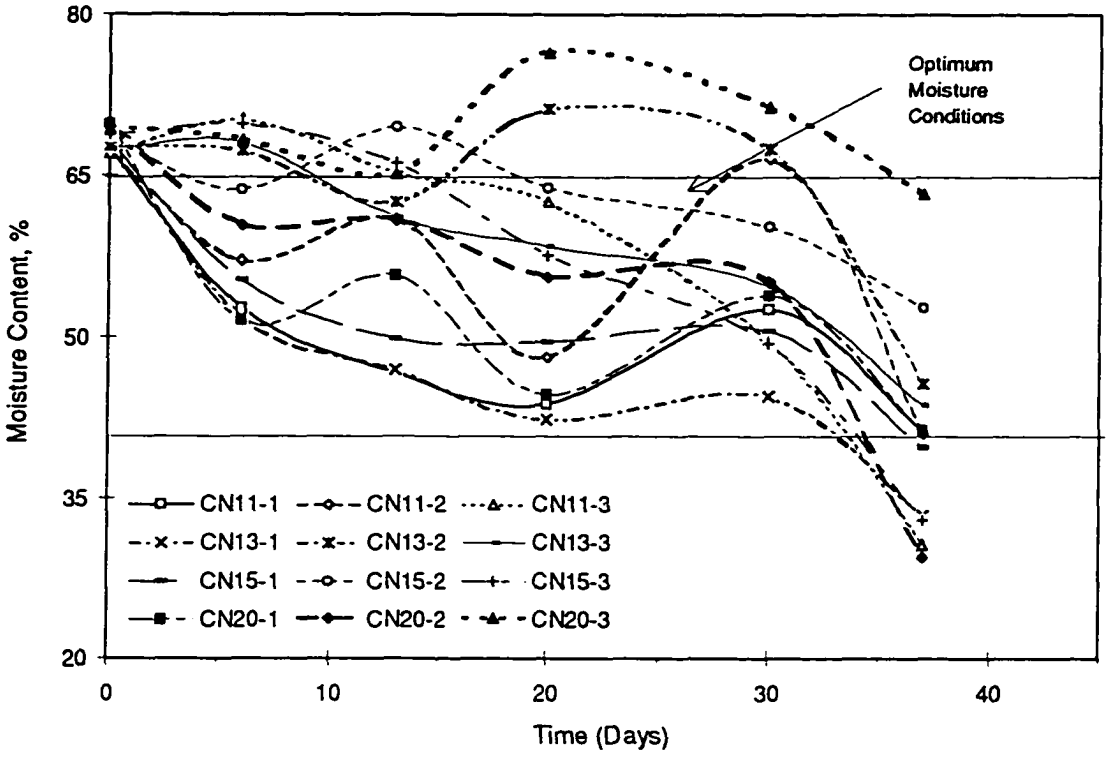



Figure B.8. Variation of compost moisture content (wet mass basis) with time in all 12 reactors during phase II.

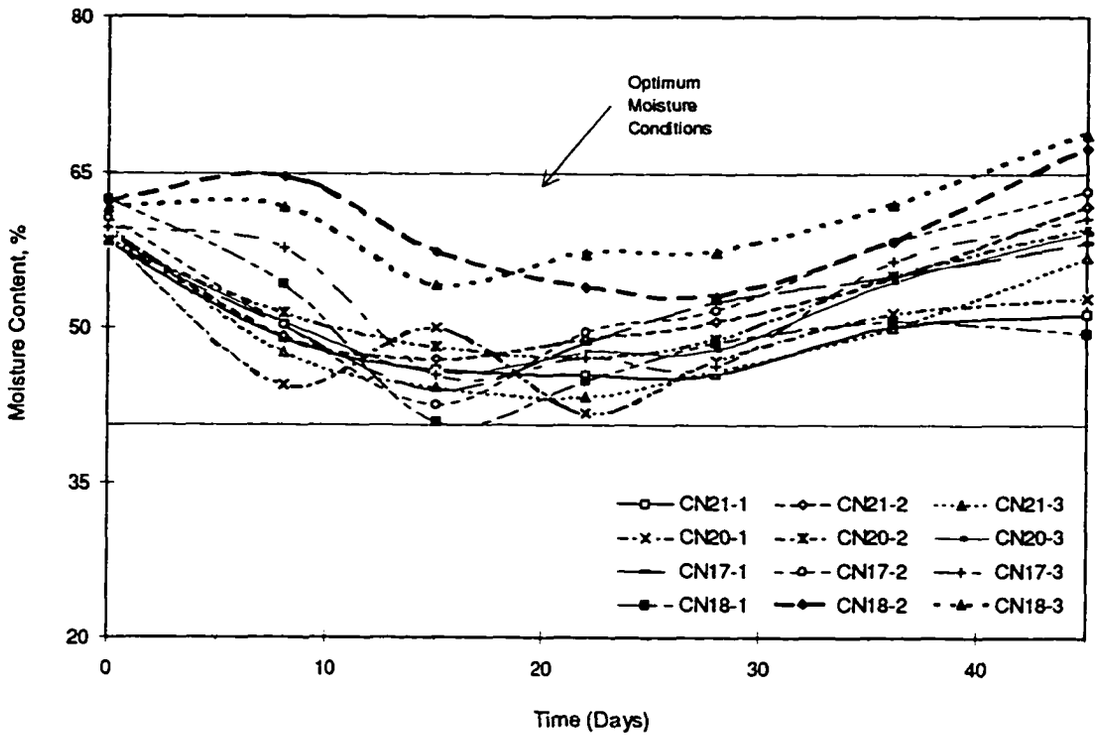



Figure B.9. Variation of compost moisture content (wet mass basis) with time in all 12 reactors during phase III.

# APPENDIX C

## PERMISSION TO REPRINT

**THE JG PRESS, INC.**
419 STATE AVENUE
EMMAUS, PENNSYLVANIA 18049
(610) 967-4135 Fax (610) 967-1345 biocycle@aol.com

PUBLISHERS OF
BioCycle In Business COMPOST
SCIENCE & UTILIZATION

FAX: 504; 388-3492

TO: Mounir Y. Minkara, Ph.D.
Louisiana State University
Baton Rouge, LA 70803-4505

DATE December 31, 1997

SUBJECT

FROM: Jerome Goldstein

Dear Dr. Minkara:

We are pleased to provide you with permission from Compost Science & Utilization to include the paper, "CoComposting of Crawfish and Agricultural By-Products" as part of your Ph.D. Dissertation

Our best wishes to you for 1998.

Sincerely,

Jerome Goldstein

# VITA

Mounir Minkara, son of Yehia Minkara and Aida Abedine, was born on February 20, 1970, in Tripoli, Lebanon, where he attended the National Orthodox College and graduated in 1987. In September 1987, he entered the University of Toledo, Toledo, Ohio. In September 1988, he transferred to the University of Georgia, Athens, Georgia, and received a degree of Bachelor of Science in Agricultural Engineering in March 1991. In September 1991, he entered the Graduate School, Auburn University, and received a degree of Master of Science in Agricultural Engineering on June 8 1994. In August 1994, he entered Louisiana State University to pursue a Ph.D. in Engineering Science in the Department of Biological and Agricultural Engineering with minors in Environmental Studies and Chemical Engineering.

## DOCTORAL EXAMINATION AND DISSERTATION REPORT

**Candidate:** Mounir Yehia Minkara

**Major Field:** Engineering Science

**Title of Dissertation:** Characterization and Biodegradation of Crawfish and Agricultural Processing By-Product Compost

**Approved:**

Thomas B. Lawson
**Major Professor and Chairman**

**Dean of the Graduate School**

**EXAMINING COMMITTEE:**

Hunter Hartzog

Ralph Portier

Raye Kupchella

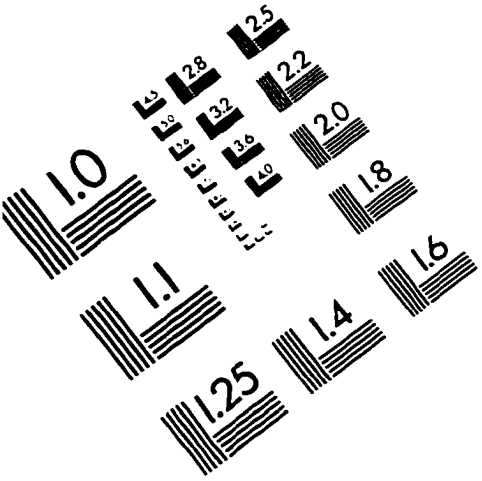
Gary Breitenbeck

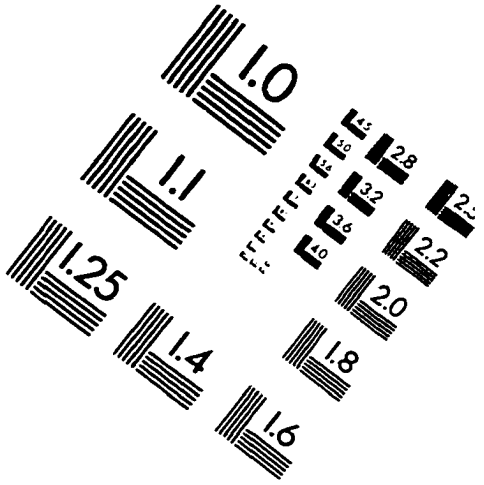
Stephen A Harrison

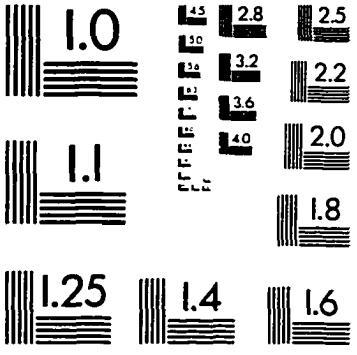
**Date of Examination:**

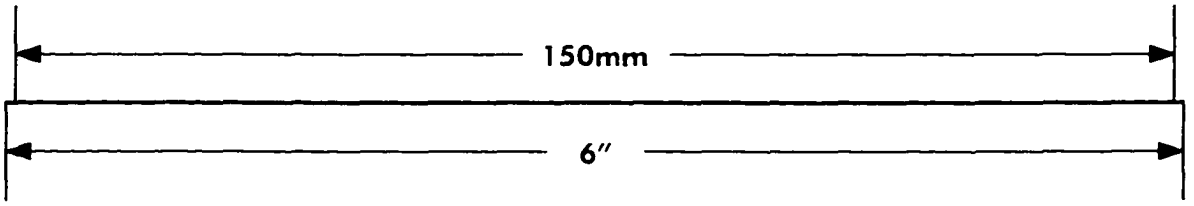
October 28, 1997

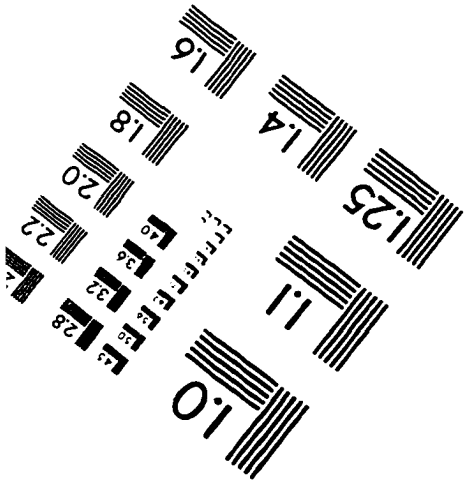
# IMAGE EVALUATION TEST TARGET (QA-3)

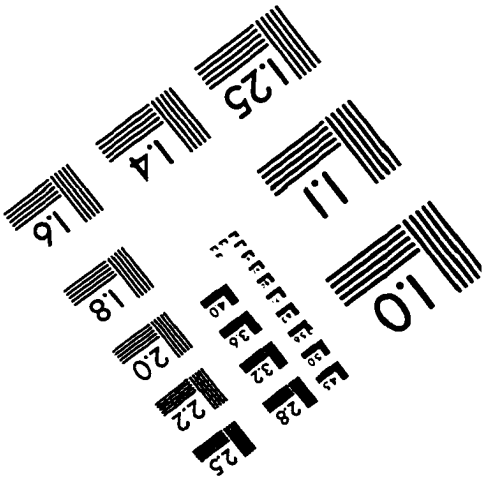



APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989